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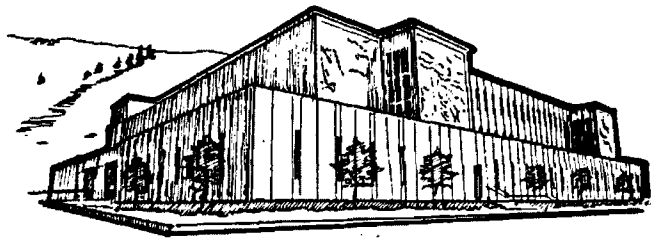
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University of  
**Montana**



AN ECOLOGICAL STUDY OF A REGULATED PALOUSE PRAIRIE STREAM

By

Juan Bosco Imbert

B. S., Basque Country University (Spain), 1986

Presented in partial fulfillment of the requirements


for the degree of

Master of Arts

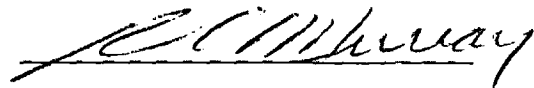
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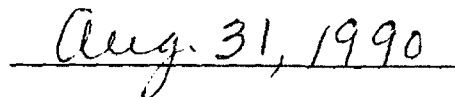
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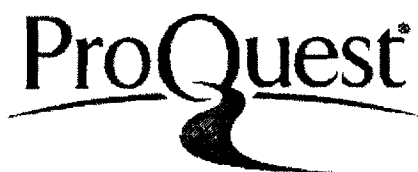


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## An Ecological Study of a Regulated Palouse Prairie Stream (65 pp.)

Director: Jack A. Stanford 

Samples were collected over a one year period at sites 150 m, 1230 m, 4590 m and 6390 m downstream from a hypolimnial release reservoir to document how Crow Creek, a Western Montana Palouse Prairie stream, has responded to regulation by an irrigation dam. Stream regulation has modified the thermal regime and the hydrograph downstream from the dam. In addition, due to (1) the particular characteristics of the reservoir (eg., shallowness, unprotected shorelines), which apparently favored mixing and sediment re-suspension caused mainly by wind action, and (2) the additive effect of agricultural run-off, dramatic changes in turbidity and nutrient concentrations occurred below the reservoir.

Seasonal changes in macroinvertebrate community structure below the reservoir occurred as a result of shifts in the relative dominance of certain taxa and temporal turnover of species. Based on detrended correspondence analysis (DCA), conductivity, temperature, dissolved oxygen and nitrates + nitrites were the variables most associated with seasonal macroinvertebrate biomass. Changes in taxa composition from the reservoir to the mouth were mainly related to species additions from site to site. Downstream changes in pH and substrata appeared to be associated with changes in biomass community structure from the reservoir to the mouth. On the other hand, DCA performed on abundances and presence/absence emphasized pH, total ammonia, discharge and substrata. Annual biomass evenness and H' units increased from the reservoir to the mouth. However, different patterns were observed when density units were used. Samples taken for comparative purposes above the reservoir during spring and summer, showed that community composition throughout the prairie segment of the stream was very different than that present at a site located at the foothills of the Mission Range, which is a natural border of the Palouse Prairie in the area. However, community composition at the regulated sites near the mouth of Crow Creek was similar to that at a site located immediately above the reservoir, suggesting that the effects of regulation ameliorated significantly in a downstream direction. The occurrence of warm water species such as *Cheumatopsyche* sp., *Helicopsyche* sp., *Petrophila* sp., *Tricorythodes* sp., and *Argia* sp. below the reservoir may indicate that a remnant fauna of the Palouse Prairie ecosystem still exists in the creek. In spring and summer, biomass of benthic fauna increased from the Mission Range to the tailwaters. Numbers and biomass of non-game fish below the reservoir increased in a downstream direction.

## ACKNOWLEDGMENTS

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Confederated Salish and Kootenai Tribes, particularly Rhonda Swaney, Ginger Thomas, Joe DosSantos, Les Evarts, Francis Durgeloh, Dane Morigeau, all the tribal dam operators and Bob Ringo (BIA), Ed McKay (BIA) and Robbin Wagner (MF&W) for all kinds of support throughout this project. My entire sympathy for the Montana Largescale Sucker Fan Club which encouraged me to count hundreds of suckers in Crow Creek.

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## INTRODUCTION

Changes in channel morphology (Simons, 1979; Trotzky & Gregory, 1974), chemistry (Hannan, 1979), temperature (Ward, 1976b; Ward & Stanford, 1979), flow (Ward, 1976a and 1984), fauna (Armitage, 1984; Holden, 1979), and flora (Ward, 1974) typically occur in the tailwaters of hypolimnial release reservoirs. These biotic and abiotic changes must be quantified in order to fully understand the ramifications of stream regulation in any particular river system.

Stream regulation in the Flathead Basin has been documented in numerous studies (see review by Stanford, 1990). However, there is a lack of information in the Lower Basin, particularly in lowland tributaries of the Flathead River in which problems derived from agricultural run-off overlap with regulation effects. Moreover, these tributaries may play an important role in the recovery of trout fisheries in the Lower Flathead River, which have been severely compromised by the effects of stream regulation by Kerr Dam (Cross *et al.*, 1988).

An integrative study was carried out in Crow Creek, one of the major tributaries of the Lower Flathead River, located within the Flathead Indian Reservation. The study was conducted during a one year period to document how the stream environment has responded to regulation by an irrigation dam. The purpose of the study was to provide basic information on the physical, chemical and biological attributes of the creek. These data may be helpful to Tribal fisheries biologists in developing a management strategy to maximize water quality and trout

production in the creek. The project also provided the first documentation of a lowland stream (ie., characteristic of the Palouse Prairie biotope) in the Flathead River Basin.

Within this context, the aim of this paper is (1) to examine longitudinal and seasonal changes in physical, chemical and biological variables below the reservoir (conditions above the reservoir are also considered for spring and summer) (2) to make inferences about how the ecology of a Palouse Prairie stream has been altered by regulation, which would be an original contribution to the understanding of lowland streams in the northwestern cordillera.

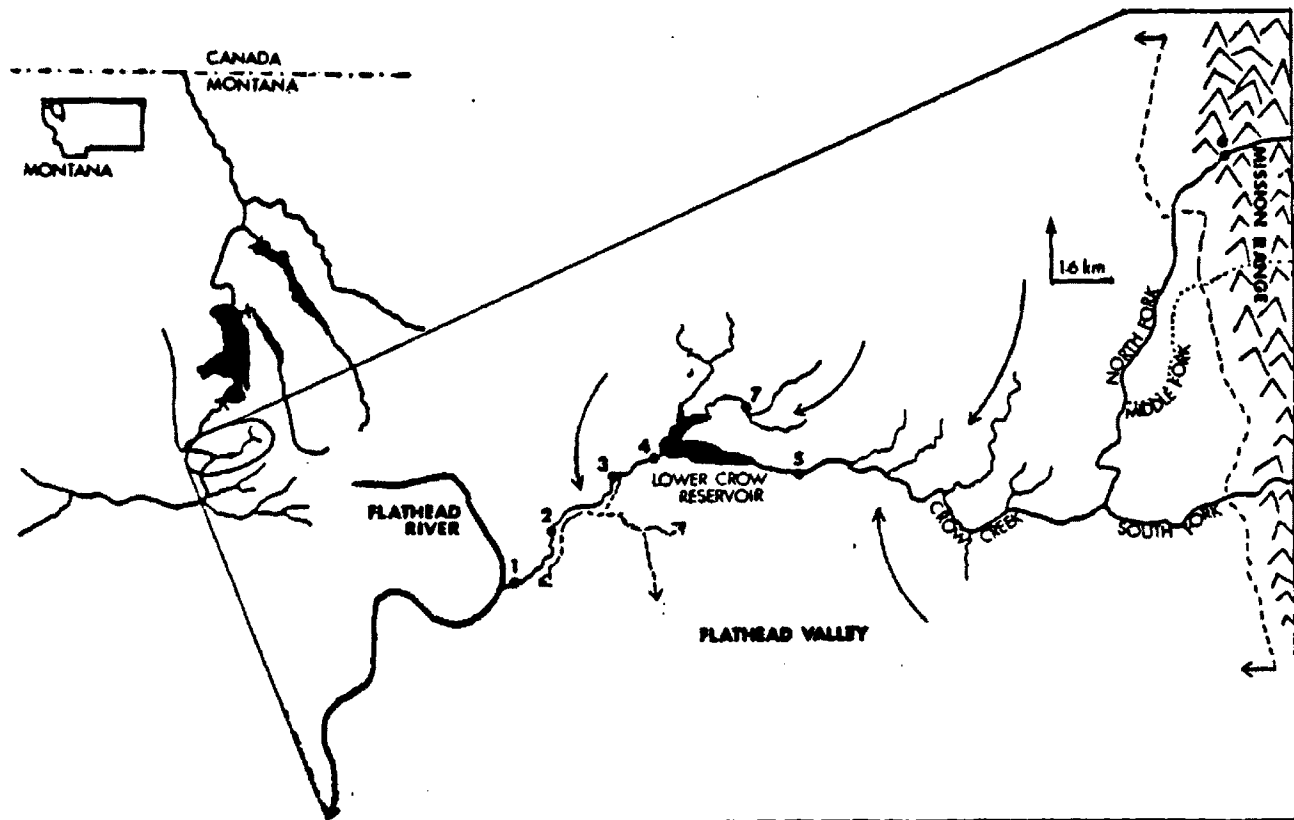
## STUDY AREA

Crow Creek originates at 3160 m in the Mission Mountains of Northwest Montana. Three high gradient tributaries flow west from the mountains and join on the broad, flat Flathead valley within the Flathead Indian Reservation to form the mainstem of Crow Creek (figure 1). The mainstem of the creek flows about 24 km across the valley to join with the Flathead River. Once the creek reaches the valley, flows are diverted by irrigation canals. However, the original main channel of the creek retains water and flows through the flat valley forming a series of meanders until it is impounded by Lower Crow Reservoir. The reservoir covers 138 hectares at full pool and releases water through an hypolimnial outlet. During the spring run-off period, excess water is released from a spillway .

The regulated segment of primary interest in this study extended a distance of approximately 6.6 km from the dam to the Flathead River. Four riffles were sampled in this segment all year around and three more were sampled above the reservoir between May and August, 1989 (see figure 1).

Site 1, was located 6.39 km below the dam. At this location the stream banks were lined with abundant grasses during the growing season but riparian canopy was limited. Hence, this site received more solar insolation than the others. The substrata consisted of loose rubble. The hydrophyte *Ranunculus longirostris* was very common in this riffle from spring run-off to December. Other aquatic plants present in the channel

Fig. 1. Location of sampling sites on Crow Creek, Northwestern Montana. Sites 1-4 were regulated by Lower Crow Reservoir. Sites 5 and 7 were influenced by irrigation return flows, shown by arrows. Primary irrigation diversions are shown by broken lines.



were *Zannichellia palustris* and *Elodea nuttalli*. The latter was very abundant in the margins and areas with slower flow. The channel was totally ice covered during extreme winter conditions.

Site 2, was located 4.59 km below the dam within a canyon section that ends a few hundred meters above site 1. Here the substrata were very similar to that found at site 4, with many cobbles and silted banks. The same hydrophytes occurred in this riffle, although beds of *Ranunculus* tended to be larger. Ice cover occurred on the shoreline and slush was suspended in the water on cold days during the winter.

Site 3, was located 1.23 km below the dam, immediately downstream from an irrigation diversion which includes a small weir crossing the channel, a screen to limit movement of fish into the irrigation canal and a fish ladder. Before the construction of this fish screen and initiation of minimum flow criteria of 21 cfs, water diversion into the canal periodically dewatered Lower Crow Creek resulting in significant fish losses and damage to the aquatic resources (Ringo & Halfmoon, 1990). Boulders were more common here than in sites 2 and 4. Hydrophytes coverage was significantly reduced relative to sites 1 and 2. Patches of moss occurred across the channel. The channel was ice free during the winter. Some beaver dams occur between this site and site 1.

Site 4 was located 0.150 km in the tailwaters. The substrata, which were heavily matted by moss and algae, consisted mainly of an armored layer of cobbles too large to be transported by the existing hydraulic conditions. During high flow periods this riffle became a run.

Relatively cold and warm temperatures occurred during summer and winter respectively, as a result of deep hypolimnial releases from the reservoir. The channel was free of ice during the winter.

Site 5 was located, 1.17 km above the reservoir. The substrata consisted mainly of boulder and cobbles in the middle of the channel and cobble and pebbles close to the banks. *Elodea nuttalli* occurred in the least turbulent areas and this was the only site where sponges were found on the rocks.

Site 6 was located 14.65 km above the reservoir, within the mouth of the canyon at the base of the Mission Range. Bedrock and boulders dominated the channel substrata with cobble and pebble filling the interspaces. The percentage of gravel was significantly higher here than in downstream sites. The riparian vegetation was very dense and consisted of alder, dogwood in Douglas-Grand fir formation with some western cedar characteristic of canyon segments of Western Montana mountain ranges (Pfister, 1977). Lots of tree branches hung over the channel.

Site 7 was a riffle located in Mud Creek, a small tributary of the reservoir (see figure 1), which receives run-off from the surrounding farmlands. Only water samples were analyzed at this site (see appendix 1). During high flows Mud Creek and a small spring accounted for approximately 10% of the water entering the reservoir.

The riparian vegetation below Crow Creek dam and at site 5 consisted of willow (*Salix*), juniper (*Juniperus*), hawthorn (*Crataegus*), and cottonwood (*Populus* sp.) trees. Shrubs and grasses were heavily



grazed by cows. Several very small springbrooks enter the creek as tributaries below the dam and several intermittent side channels contribute rubble substrata and sediments to the system during spates (particularly in the canyon section and above site 4).

The Mission Range is formed by precambrian mudstones of the Belt Series (Ross, 1959) that do not yield much buffer capacity. Lack of dissolved solids was evident at site 6, which is located within the mountain canyon where the creek remains pristine. The valley was formed by Pleistocene glaciation, and deposits of till and alluvium are common landscape features. There are also extensive lacustrine sediments from the neoglacial Lake Missoula. Outcrop of these sediments are common in the regulated segment of the creek, and seem to be the origin of sediments in Crow Creek. The valley is extensively farmed but today is mostly pasture land. Many areas are overgrazed, specially along the creek corridors (figure 1).

## MATERIAL AND METHODS

Starting in September 1988, three benthic samples per site were collected approximately every two months for one year. Physical measurements and chemical samples were taken approximately every 30 days. The sites above the reservoir were sampled in April 1989 and until the end of the study period. Sites were sampled in an upstream direction.

### Discharge

Discharge data were provided by the dam operators of the Confederated Salish and Kootenai Tribes. Data were obtained from two staff gauges, one a few meters above site 4 and the other below the irrigation diversion.

### Substratum

A visual method was used to make a rapid evaluation of the percentage composition of five substratum classes in the six study sites (Boulder >256 mm, cobble 64-256 mm, pebble 16-64 mm, gravel 2-16 mm, sand and smaller material <2 mm). This method was applied only once because of consistently poor visibility of the substrata caused by turbidity in the water. A 0.25 m metal frame was tossed in an upstream direction along three parallel imaginary lines (middle of the channel, submiddle and thalweg) and the substratum composition was determined at five points per subsection. A summary of percentage substratum composition is given in appendix 2. Average substratum percentages per subsection ( $\log(\text{each substratum class}+1)$ ) were related to DCA ordination

scores in multivariate analyses. Because these values corresponded to a single date, it was assumed that no significant changes within the substratum at each site occurred during the study period. Indeed, there was no visual evidence that such changes may have occurred.

#### Temperature and oxygen

Temperature (TEMP) and dissolved oxygen (DO) were measured in the field with a YSI 54 meter. In addition to the monthly measurements diel cycles for both parameters were measured in October 11, 1988; April 20, 1989 and August 29, 1989. Only a few readings were taken in sites 1 and 4 on February 15, 1989 due to cold temperatures and the heavy snow cover.

#### Water chemistry

Two water samples were taken from just below the surface at mid-channel by opening a 1000 ml polyethylene bottle and closing it again under water after filling. The bottles were previously rinsed once with 10% HCL and twice with deionized water in the lab, and two more times with stream water in the sampling site before filling. Samples for soluble reactive phosphorus (SRP), total ammonia ( $\text{NH}_3\text{-N}$ ) and nitrates + nitrites ( $\text{NO}_3/2$ ) were filtered (membrane filter GN-6, 0.45  $\mu\text{m}$ ) in the field using a hand -operated vacuum pump at 207 kPa (30 psi) maximum and frozen in a cooler with dry ice. Samples for particulate organic matter (POM) were also filtered in the field (glass fiber filter Gelman, type A/E 47mm). Unfiltered samples for total persulfate nitrogen (TPN) and

total phosphorus (TP) were also frozen in the field. Samples for pH, total alkalinity (ALK), specific conductance (COND), turbidity (TURB) and total suspended solids (TSS) were kept in a separate cooler on ice until arrival back at the lab where they were immediately analyzed. pH was measured on two occasions in the field to assess possible changes in values during the trip back to the lab, but very small differences were detected. The reservoir, inlets and the outlet were sampled in July and August, 1989 (see sites locations in appendix 3). DO, specific conductivity, pH and temperature were measured using a Hydrolab Surveyor II. Additional readings included turbidity, TSS and Secchi disk. All laboratory analyses (Table I) followed detailed procedures described in Stanford *et al.* (1986) and approved by the U. S. Environmental Protection Agency.

#### Zoobenthos

Aquatic macroinvertebrates were collected by using a quantitative kick net which employs a 125  $\mu\text{m}$  mesh and operates on the same principle as a Surber sampler (Hauer & Stanford, 1981). A 0.25  $\text{m}^2$  frame was tossed to the channel in three points from the middle of the channel to the thalweg, moving each time in an upstream direction. The net was placed downstream of the frame and the macroinvertebrates within this delineated area were detached by hand from the substratum during 45 seconds; after this process the substratum was moved by kicking for 15 seconds. Samples were preserved with 10% formaldehyde in jars for later sorting, identification and counting of macroinvertebrates.

TABLE I. Methods and instruments used in the Freshwater Lab to analyze physical and chemical variables. (1)= APHA (1985); (2)= D'Elia *et al.* (1977); (3) Hewlet-Packard. (1971).

VARIABLE (units)	METHOD	DETECTION LIMIT	INSTRUMENT
phosphorus (ug/l) total	persulfate digestion; modified automated ascorbic acid (1)	0.5	Technicon AAI
soluble reactive Nitrogen (ug/l)	filtration; mod. aut. as. acid(1)	0.4	Technicon AAI
total persulfate	persulfate dig.(2); auto. cadmium reduction (1)	20.0	Technicon AAI
nitrate + nitrite	auto. cadmium reduction (1)	2.0	Technicon AAI
total ammonia	auto. phenate (1)	2.0	Technicon AAI
POC (ugC/l)	thermal conductivity (3)	50.0	Hewlet-Packard F&M model 185
PN (ugN/l)	thermal conductivity (3)	10.0	H-P F&M model 185
Tot. alk. (mg/l CaCO <sub>3</sub> )	titration (1)	0.5	Corning pHmeter 130
pH	electrode	0.05	Corning pHmeter 130
Spec. cond. (umhos/cm)	electrode	1.0	Amber Science 1052 A
TSS (mg/l)	filtration; drying at 103 °C (1)	0.5	
Turbidity (NTU)	nephelometry (1)	0.1	Hatch model 2100 A

In the lab, each sample was emptied into a pan and all large conspicuous macroinvertebrates were sorted out. When very high numbers of certain taxa (eg., Chironomidae) were found, a small subsample was sorted. After removing large invertebrates, the sample was separated into different categories (eg; macrophytes, silt);  $1/4$  of each category was taken to be analyzed under the microscope in order to enumerate very small organisms. Less common taxa were always subsampled by  $1/4$ . Two  $1/16$  subsamples were taken for the more common taxa and additional  $1/16$  subsamples were taken if the numbers obtained for each pair of subsamples were very different. In general  $1/8$  of the total sample of common invertebrates was analyzed under the microscope. Biomass was determined as dry mass per taxon, by drying the macroinvertebrates at  $60^{\circ}\text{C}$  for 12 hours and weighing the samples on an AND electronic balance, model ER-182 A.

Longitudinal and temporal changes in diversity both for abundance and biomass were measured by using the Shannon-Wiener function (Krebs, 1985). All taxa were considered in the analysis. For this purpose identification was performed to the minimum taxonomic level possible by using the keys and expertise available. It is recognized that this fact limits comparisons to the first five sites given that their taxa composition was very similar, and that comparisons with site 6 are restricted. The functions were:  $H' = - \sum p_i \log p_i$  and  $E = H' / \log S$ , where  $H'$  = specific diversity,  $E$  = evenness,  $S$  = number of species and  $p_i$  = probability of species "i".

## Fish

A five year plan to mitigate damage to the trout fisheries below Lower Crow Reservoir resulting from the Flathead Agency Irrigation Division (FAID) water delivery operation was carried out concurrently by the Confederated Salish and Kootenai Tribes (CS&KT) and the Bureau of Indian Affairs (BIA). The plan proposed (1) the introduction of hatchery rainbow and brown trout in the creek (2) a monitoring program to assess success of hatchery augmentation (3) the creation of artificial spawning habitat for trout.

As a part of this master's project, non-game fish population estimates were included in the biannual trout population survey during 1989. Field work was performed in cooperation with fisheries biologists from the CS&KT, BIA and Montana Fish and Game. A 400 meter section was sampled at sites 1 and 3. Length of site 4 was shortened to 225 meters due to the high number of stocked trout inhabiting that site. Before sampling, the flow was reduced gradually to approximately 20 cfs to increase visibility in the creek. Two people equipped with backpack generators (using DC current) moved downstream making passes from bank to bank. Stunned fish were collected by four people with dip-nets and deposited in live-traps. After sampling, fish were identified, counted and weighed. Partial clips of the dorsal and caudal fin were used to mark the fish. Marked fish were released in different points of the section where they were collected. Trout population data were reported elsewhere (eg., Ringo and Halfmoon, 1990). Estimates of fish populations were performed during the spring and fall of 1989 in sites 1, 3 and 4

using the Chapman's modification of Petersen's formula (Ricker, 1975) and the two pass removal method (Armour et al, 1983). The latter was used on only one occasion, in site 4 prior to the regular scheduled sampling because of the immediate need to collect and rescue fish when part of the stream channel was dewatered during a dam inspection. Statistical population estimates were made whenever conditions for an unbiased estimate were met ( $M.C > N$ ). The modified Petersen's estimation formula is:

"N" =  $\frac{(M+1)(C+1)}{R+1}$ , where M= total number of marked fish in the population.

$V(N) = \frac{N^2(C-R)}{((C+1)(R+2))}$ , where C= number of fish in the sample.  
R= number of marked fish recaptured in the sample

"N"= estimate of N.

N= total number of fish in the population

Area per section was not measured during sampling. Because mean width did not vary greatly among sections it seems reasonable to make comparisons based on length.

Riffles, pools and runs (raceways) for each site were categorized according to the criteria of Bisson *et al.* (1982) (appendix 4). Runs were dominant in all sections. The percentage of each reach characterized by riffle habitat was very similar among the different



sites. Pools were most prevalent (35% of area) below the fish ladder (section 3) and least conspicuous (21.9% of area) in the canyon section (section 2).

#### Multivariate analyses and correlations

All the multivariate analyses were performed using the PC-ORD program system (McCune 1989). Detrended correspondence analysis (DCA) (Hill, 1979b) was used to isolate structure in the environmental data in relation to sample location and to summarize the information contained in the species by samples matrix. DCA was chosen among other ordination techniques because of its superior performance in field and simulation studies (Gauch, 1982). A more powerful method (canonical correspondence analysis) to analyze species-environment relationships is provided by the program CANOCO (Braak, 1989) but it was not available for this study. Both analyses assume a unimodal response of species to environmental gradients. DCA was performed using  $\log(\text{density}+1)$ , biomass and presence/absence with no downweighting the rare species. The analysis produced a two dimensional graph where samples with similar species composition and relative abundance occurred most closely together. A similar graph based on the same principle represented all the species collected in all sites at different times. The axes can be interpreted in terms of known variation in the environment or by calculating correlation coefficients between environmental variables and each of the ordination axis (Braak & Prentice, 1988). The success of the

latter approach depends on obtaining ecologically meaningful axes. Ordination scores were related to transformed physical and chemical variables ( $\log(\text{variable}+1)$ ).

Additionally, interrelationships between the biomass scores and groups of correlated physical and chemical variables were assessed by Principal Components Analysis (PCA) (Johnson & Wichern, 1988). PCA was also performed on the chemical variables, temperature and discharge. Environmental variables were transformed to give the closest approximations to normality; this was assessed graphically by mean of histograms superimposed by a normal curve and Q-Q plots (Wilkinson, 1988). Pearson's product-moment correlations were used to find possible relationships between biomass of individual taxa ( $\log(\text{taxa biomass}+1)$ ) and physical and chemical variables ( $\log(\text{variable}+1)$ ), with the exception of pH, which is already in logarithmic form.

## RESULTS AND DISCUSSION

### Discharge

Following the spring run-off, discharge increased at site 4 (between the reservoir and the diversion, see figure 1) and reached a peak in July (figure 2). Hypolimnial discharge from the reservoir diminished in August, as a long period of rain reduced demand for irrigation water from the reservoir. Discharge below the diversion was approximately 22 cfs throughout the year, in accord with the minimum flow agreement (Ringo & Halfmoon, 1990).

### Temperature and oxygen

Temperature increased or decreased downstream from the dam, depending on season and time of day (figure 3). In general, it was relatively colder close to the reservoir from March to September and warmer for the other months (see figure 3 and table 2). Seasonal and diel fluctuations in water temperature generally increased in a downstream direction. The only exception to this pattern was observed in February when site 1 was cover by ice. On the other hand, site 4 remained ice-free and temperature oscillations during an eight hour period (light hours) were very low (2.1-2.2 °C). Maximum diel changes were observed in April (site 1, 4.5-12.0 °C; site 4, 4.4-5.0 °C). Seasonal and diel changes in oxygen and % oxygen saturation were closely related to changes in temperature. Diel changes for these two variables were higher at the two downstream sites. Although a decrease in oxygen from the mouth to the reservoir was observed diurnally in summer, % oxygen saturation was always higher than 90 %.

Figure 2. Average monthly discharge values ( $\bar{X} \pm sd$ ) recorded at site 4 (star) and site 3 (circle) during the study period.

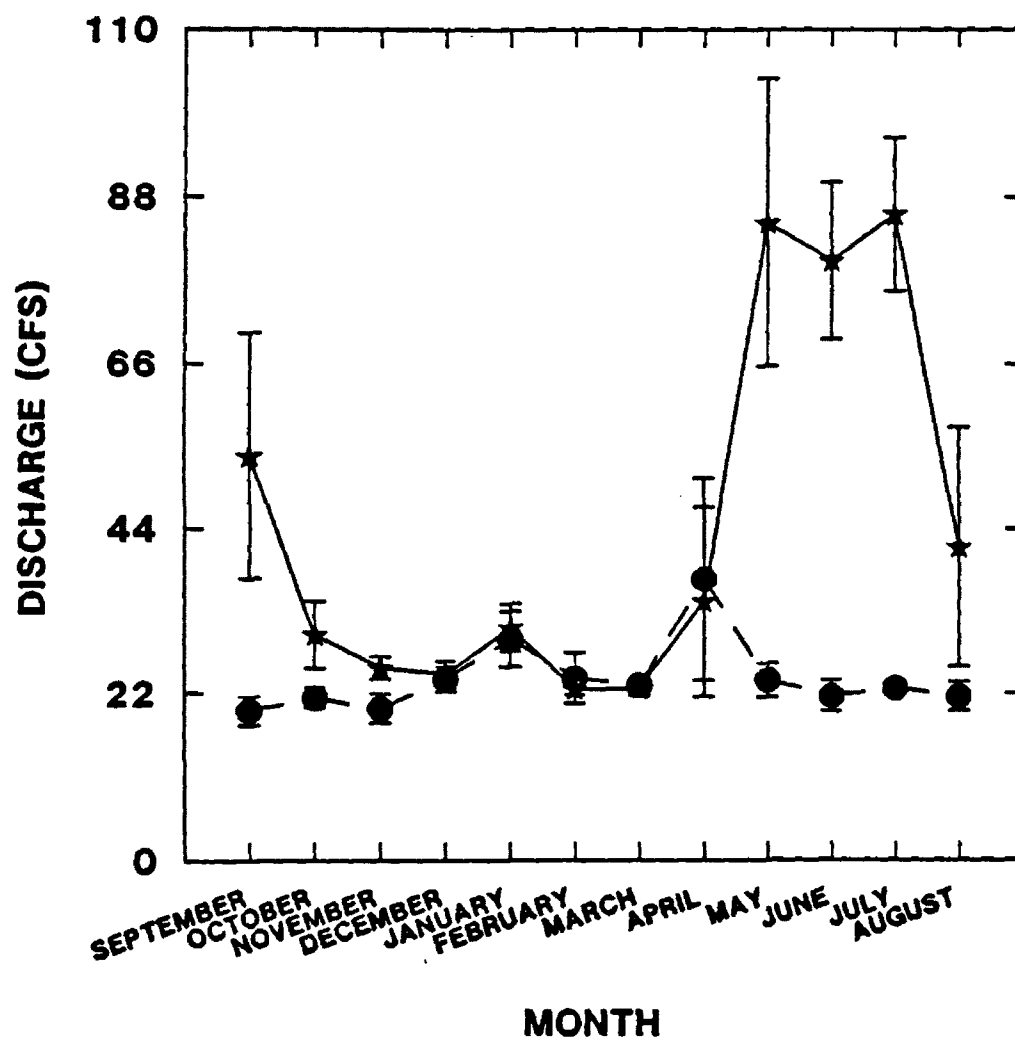
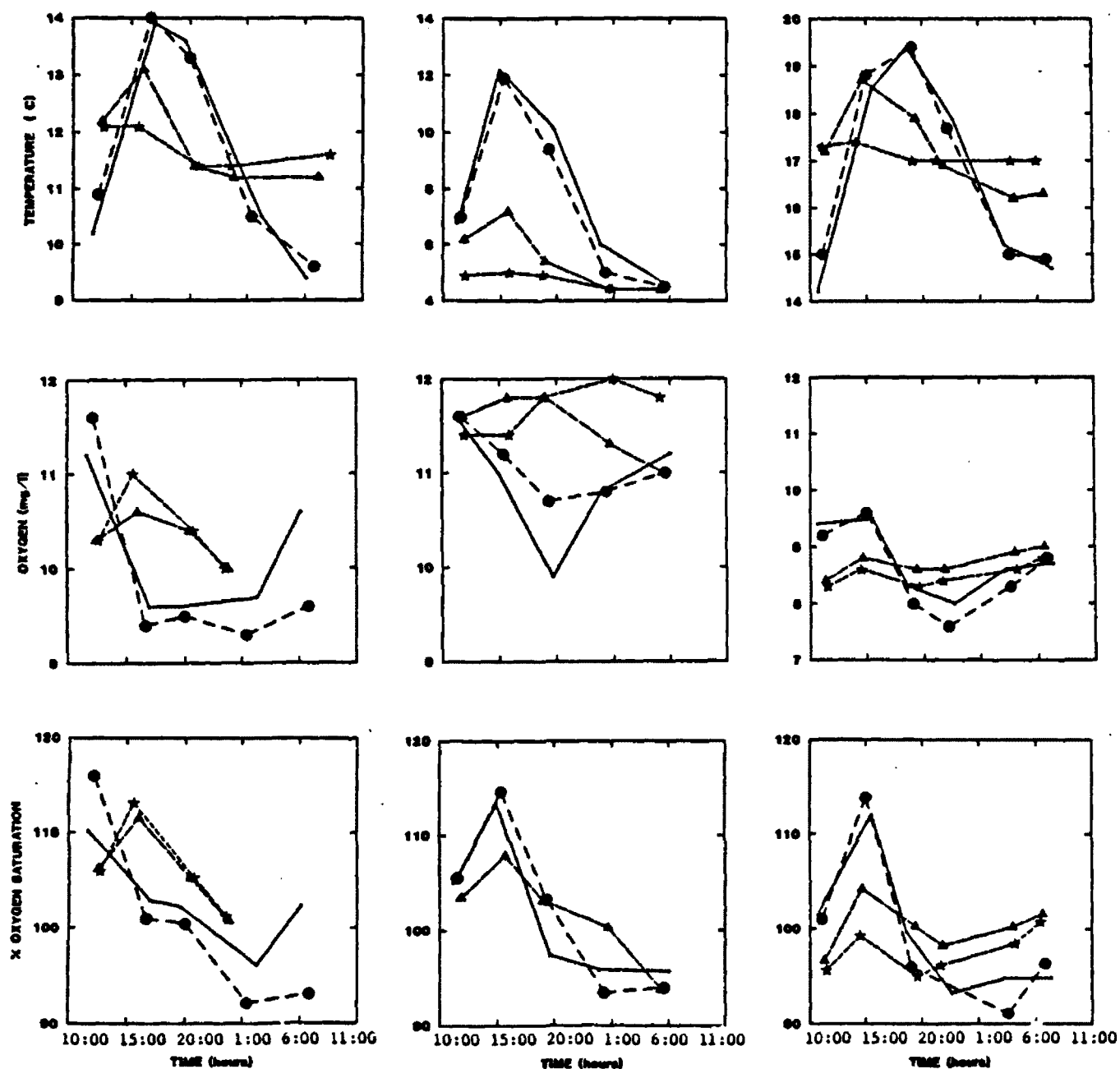


Figure 3 Diel changes of temperature, dissolved oxygen and % oxygen saturation for sites 1, 2, 3, and 4 in (A) October 11, 1988; (B) April 20, 1989; (C) August 29, 1989. Symbols denote sites: small square= site 1; circle=site 2; triangle= site 3; star=site 4.



The minimum value of oxygen (6.5 mg/l) was recorded at site 1 on February 15 under the ice cover. Oxygen values of 13.4 mg/l were measured for the same site after part of the ice cover melted later in the day. Oxygen values at site 4 for the same day ranged from 12.4 to 12.9 mg/l.

#### Water chemistry

Table II gives the average values and standard deviations for the chemical variables which are summarized according to the groupings differentiated by PCA. The most apparent problem below the reservoir was the high turbidity of the water during much of the year. The effects of sedimentation on benthic communities and spawning habitat for fish have been reported on numerous occasions (eg., Cordone and Kelly, 1961; Hynes, 1973). Turbidity was relatively higher in September, October and April. Several readings taken in September and October showed that turbidity was highly variable during these months and always decreased downstream. A peak at site 3 was detected in three out of four occasions. On the other hand, relative low values of turbidity below the reservoir coincided with an increase in turbidity in a downstream direction. Although no preimpoundment data were available, the relatively clear waters seen over the year in Crow Creek above the reservoir (personal observations, see also table II) suggest that water was more clear in the creek before the dam, irrigation and other regulation diversions were constructed in the valley.

TABLE II. Mean values ( $\bar{x} \pm s$ ) of physical and chemical variables for all the study sites grouped by months as derived from the PCA. Group I= December, January, February and March; Group II= October and November; Group III= April; Group IV= May and June; Group V= July, August and September. Two values are given for group V, one includes July and August and the other (in parenthesis) is for September. This was done in order to make comparisons with sites 5 and 6 (above the reservoir). Groups arranged seasonally.

	SITE	TEMPERATURE (°C)	pH	DO (mg/l)	% OXYG. SAT.	CONDUCTIVITY ( $\mu\text{ohms/cm}$ )	ALKALINITY (mg $\text{CO}_3\text{Ca/l}$ )	TURBIDITY (N.T.U)	TSS (mg/l)
GROUP II	1	9.80 $\pm$ 2.40	8.39 $\pm$ 0.15	10.30 $\pm$ 0.42	100.54 $\pm$ 9.92	277.50 $\pm$ 6.36	154.60 $\pm$ 1.55	22.35 $\pm$ 6.86	-
	2	9.95 $\pm$ 2.47	8.40 $\pm$ 0.13	9.95 $\pm$ 0.07	97.34 $\pm$ 5.06	275.50 $\pm$ 3.53	152.65 $\pm$ 0.35	20.35 $\pm$ 9.69	-
	3	10.00 $\pm$ 3.11	8.34 $\pm$ 0.08	10.40 $\pm$ 0.57	101.66 $\pm$ 1.99	291.00 $\pm$ 11.3	153.65 $\pm$ 4.17	36.50 $\pm$ 17.7	-
	4	9.80 $\pm$ 3.25	8.19 $\pm$ 0.01	10.40 $\pm$ 0.57	101.19 $\pm$ 2.39	284.00 $\pm$ 2.83	159.50 $\pm$ 17.1	40.60 $\pm$ 30.5	-
GROUP I	1	0.40 $\pm$ 0.60	8.26 $\pm$ 0.08	12.62 $\pm$ 0.86	97.09 $\pm$ 5.35	322.00 $\pm$ 28.72	164.17 $\pm$ 7.80	13.65 $\pm$ 2.82	-
	2	0.72 $\pm$ 0.75	8.24 $\pm$ 0.11	12.80 $\pm$ 0.53	99.29 $\pm$ 2.91	324.25 $\pm$ 24.80	164.45 $\pm$ 7.49	18.00 $\pm$ 4.76	-
	3	2.42 $\pm$ 0.26	8.22 $\pm$ 0.10	12.55 $\pm$ 0.33	101.75 $\pm$ 2.0	318.25 $\pm$ 21.31	161.97 $\pm$ 7.64	12.50 $\pm$ 4.81	-
	4	2.45 $\pm$ 0.44	8.16 $\pm$ 0.12	12.72 $\pm$ 0.17	103.22 $\pm$ 1.1	321.75 $\pm$ 19.40	161.82 $\pm$ 5.84	12.62 $\pm$ 9.44	-
GROUP III	1	3.3	8.24	11.4	94.53	265.00	107.80	56.50	-
	2	4.9	8.27	11.2	96.69	271.00	119.90	53.00	-
	3	3.6	8.24	12.3	102.76	290.00	134.20	41.00	-
	4	3.0	7.91	12.4	101.98	297.00	134.20	43.00	-
GROUP IV	1	12.65 $\pm$ 0.49	8.72 $\pm$ 0.17	11.10 $\pm$ 0.99	115.59 $\pm$ 9.00	290.00 $\pm$ 2.83	135.85 $\pm$ 5.44	15.25 $\pm$ 1.06	29.60 $\pm$ 12.2
	2	12.60 $\pm$ 0.85	8.51 $\pm$ 0.12	10.35 $\pm$ 0.64	107.76 $\pm$ 8.76	288.00 $\pm$ 0.00	133.25 $\pm$ 6.01	15.25 $\pm$ 0.35	28.35 $\pm$ 13.2
	3	9.95 $\pm$ 2.19	8.19 $\pm$ 0.06	10.10 $\pm$ 0.42	98.68 $\pm$ 1.07	285.50 $\pm$ 3.53	132.00 $\pm$ 3.11	14.25 $\pm$ 6.01	21.95 $\pm$ 3.75
	4	8.00 $\pm$ 3.11	7.99 $\pm$ 0.00	10.25 $\pm$ 1.20	95.27 $\pm$ 3.91	288.50 $\pm$ 3.53	134.75 $\pm$ 3.89	12.65 $\pm$ 5.35	20.20 $\pm$ 11.0
	5	17.14 $\pm$ 0.85	8.25 $\pm$ 0.03	9.5 $\pm$ 0.14	109.66 $\pm$ 0.22	157.00 $\pm$ 14.1	75.35 $\pm$ 5.44	5.95 $\pm$ 0.78	13.20 $\pm$ 0.85
	6	4.95 $\pm$ 0.64	7.21 $\pm$ 0.17	10.95 $\pm$ 0.21	94.64 $\pm$ 0.32	35.50 $\pm$ 4.95	14.85 $\pm$ 0.78	3.00 $\pm$ 2.83	1.00 $\pm$ 0.14
GROUP V	1	16.55 $\pm$ 2.76 (16.41)	8.46 $\pm$ 0.11 (8.85)	9.40 $\pm$ 0.57 (10.06)	106.40 $\pm$ 0.35 (113.79)	241.00 $\pm$ 16.97 (235.00)	116.6 $\pm$ 12.44 (106.40)	10.35 $\pm$ 2.33 (9.40)	18.22 $\pm$ 4.06
	2	17.70 $\pm$ 3.11 (21.91)	8.41 $\pm$ 0.10 (8.71)	9.20 $\pm$ 0.28 (8.78)	106.69 $\pm$ 3.33 (110.11)	232.00 $\pm$ 16.97 (211.00)	114.4 $\pm$ 9.33 (106.90)	9.05 $\pm$ 1.34 (16.0)	15.20 $\pm$ 3.68
	3	18.35 $\pm$ 2.90 (18.70)	8.12 $\pm$ 0.03 (8.22)	8.40 $\pm$ 0.49 (8.57)	99.14 $\pm$ 0.18 (101.52)	223.50 $\pm$ 17.68 (216.00)	108.35 $\pm$ 10.1 (100.00)	8.85 $\pm$ 0.92 (43.0)	10.95 $\pm$ 2.90
	4	17.90 $\pm$ 2.69 (18.44)	7.97 $\pm$ 0.01 (8.11)	8.50 $\pm$ 0.71 (8.92)	98.81 $\pm$ 2.96 (105.10)	223.00 $\pm$ 18.38 (229.00)	110.55 $\pm$ 8.55 (102.3)	7.60 $\pm$ 1.41 (38.0)	9.50 $\pm$ 3.81
	5	19.85 $\pm$ 1.20	8.37 $\pm$ 0.00	8.50 $\pm$ 0.00	102.85 $\pm$ 2.29	164.50 $\pm$ 77.8	82.50 $\pm$ 3.11	4.00 $\pm$ 1.41	6.75 $\pm$ 0.21
	6	8.10 $\pm$ 1.27	7.57 $\pm$ 0.10	9.90 $\pm$ 0.14	92.54 $\pm$ 1.54	73.50 $\pm$ 9.19	37.95 $\pm$ 3.89	0.95 $\pm$ 0.35	0.20 $\pm$ 0.14

TABLE II. Continued. PN and POC samples for August are missing. NMP= no measurable peak.

	SITE	NH <sub>3</sub> -N (ug/l)	NITRATE-NITRITE (ug/l)	TPN (ug/l)	PART. NITR. (ug/l)	SRP (ug/l)	TOTAL PHOSP. (ug/l)	PART. ORG. CARBON (ug/l)
GROUP II	1	18.30±8.06	310.00±53.74	-	218.50±47.38	17.05±14.2	-	1260.50±161.93
	2	14.10±2.83	328.50±43.13	-	208.00±21.21	4.65±2.33	-	1319.50±461.74
	3	43.05±0.07	359.50±2.12	-	311.50±112.43	6.55±1.34	-	2031.50±690.84
	4	78.05±24.1	314.00±82.02	-	286.00±200.82	5.70±0.71	-	2169.50±1622.81
GROUP I	1	34.17±12.63	790.00±97.91	-	133.25±17.73	14.42±6.47	-	997.75±158.69
	2	51.86±33.54	779.50±104.7	-	188.75±26.33	16.27±9.44	-	1430.30±461.19
	3	75.30±54.00	773.75±91.78	-	179.50±112.74	21.25±13.8	-	1087.50±448.27
	4	83.80±46.31	780.75±103.7	-	160.00±84.63	25.77±24.3	-	1014.75±552.72
GROUP III	1	949.00	44.9	2114.00	579.00	283.00	426.00	4065.00
	2	581.00	417.00	2054.00	491.00	264.00	714.00	1496.00
	3	521.00	467.00	2165.00	701.00	210.00	324.00	3918.00
	4	680.00	467.00	2448.00	517.00	226.00	328.00	1770.00
GROUP IV	1	149.15±84.64	319.00±141.42	975.50±345.47	258.50±129.40	95.1±1.1	140.50±36.06	1091.50±521.14
	2	101.30±70.29	353.50±111.02	1018.00±315.37	215.00±70.71	107.3±16.5	133.50±19.09	1137.50±791.25
	3	435.00±243.2	308.50±129.40	1136.50±307.59	150.50±12.02	113.5±6.4	151.00±18.38	1259.00±69.30
	4	629.50±463.5	325.50±193.04	1187.50±333.05	157.00±2.83	150.0±24.0	181.00±43.84	926.50±214.25
	5	27.25±4.74	21.05±7.85	332.00±89.05	103.50±7.78	47.2±31.7	69.60±35.07	899.00±246.07
	6	20.50±12.23	39.20±23.90	116.25±43.49	15.00±21.20	3.25±0.9	6.75±4.45	235.00±117.38
GROUP V	1	21.25±1.20 (10.80)	279.00±130.11 (56.00)	729.00±173.95	159.50±95.46 (121.00)	117.95±28.35 (49.60)	179.50±44.54	1061.00±620.84 (926.00)
	2	28.25±8.70 (20.90)	291.00±113.14 (93.50)	740.00±182.43	160.00±53.74 (134.00)	125.95±39.67 (56.20)	193.00±45.25	946.50±400.93 (590.00)
	3	218.50±19.1 (88.70)	166.50±41.72 (114.00)	926.00±147.08	174.00±118.79 (206.00)	174.50±81.32 (73.40)	230.00±76.37	745.50±620.13 (1043.00)
	4	530.50±191.6 (153.00)	51.85±20.58 (53.80)	841.00±199.40	62.00 (July) (192-346)	178.55±118.0 (48.20)	157.00±28.28	436.00 (July) 450-1063 (July)
	5	24.75±3.75	29.10±25.17	224.50±12.02	102.0 (July)	41.85±14.64	56.90±7.64	386.00 (July)
	6	9.60±1.41	43.85±3.04	64.05±3.46	NMP (July)	4.30±1.70	4.15±1.63	120.00 (July)



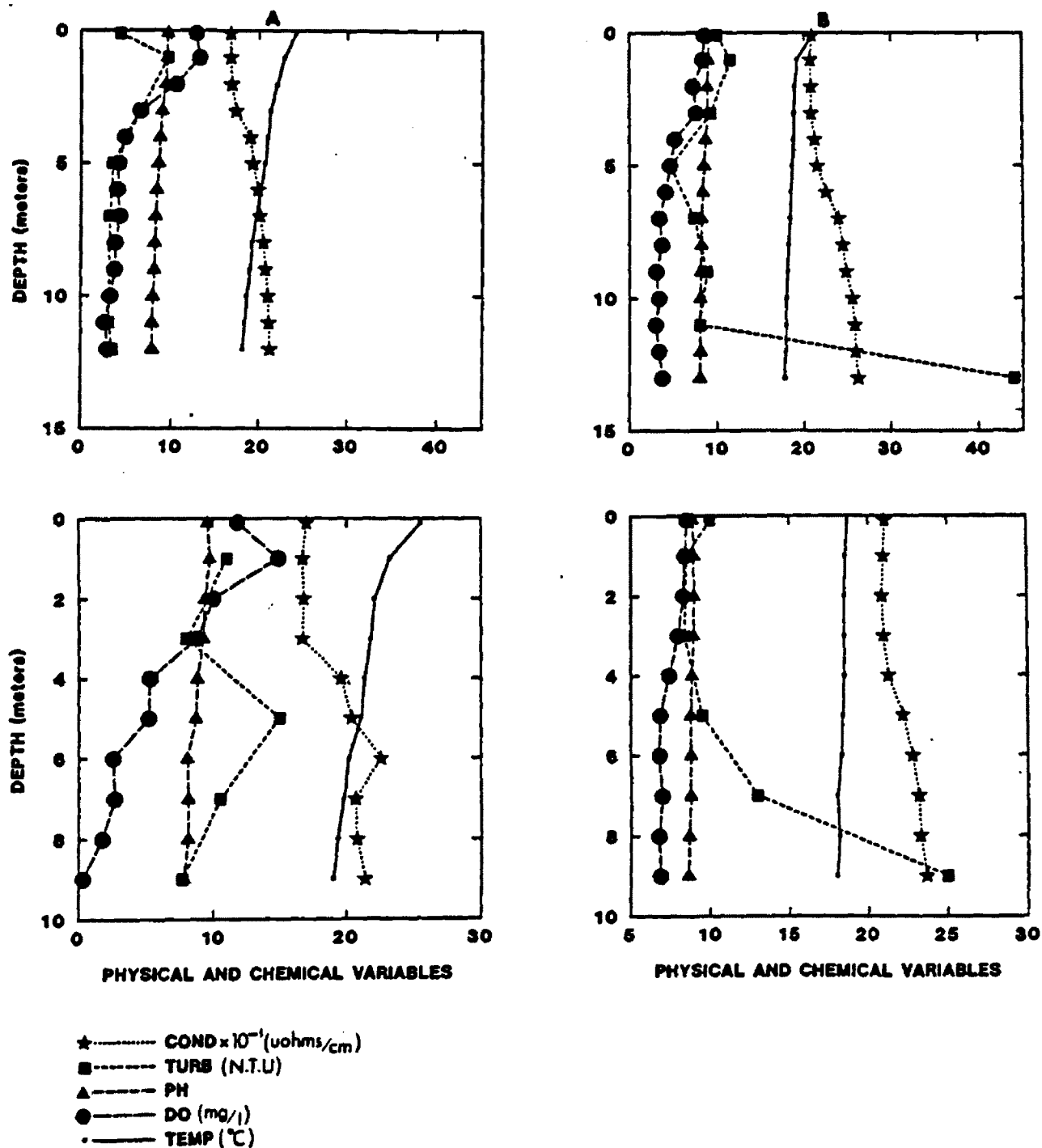
Nutrient concentrations (except  $\text{NO}_3/2$ ) were significantly higher from April (spring run-off peak) to September than in winter (table II). For instance, average  $\text{NH}_3\text{-N}$  concentrations in site 4 for the former time period were always higher than 500  $\mu\text{g/l}$  but did not exceed 100  $\mu\text{g/l}$  from October to March. The relative increase in nutrients in sites 1 and 2 during the spring run-off peak appears to have been caused by the spring freshet, especially run-off from farmlands as the snow cover melted. One of the primary consequences of these events is the stimulation of primary production in the creek. Aquatic vegetation retained sediment released from the reservoir and intermittent side channels along the creek. Conductivity and alkalinity showed the highest values at all sites from December to March (292.0-353.0  $\mu\text{ohms/cm}$  and 154.0-173.8  $\text{mg CO}_3\text{Ca/l}$  for conductivity and alkalinity respectively) and the lowest from July to September (210.0-253.0  $\mu\text{ohms/cm}$  and 100.00-130.00  $\text{CO}_3\text{Ca/l}$ ). pH average values ranged from 7.97 to 8.72 and always increased from the outlet to the mouth.

Three events seem to be important in explaining the patterns observed: 1) the mixing of the reservoir 2) the annual spring run-off and 3) the stratification of the reservoir during summer. Mixing of the reservoir apparently was caused by wind action resulting in temporary increases in turbidity and nutrient concentrations below the outlet. For instance, on January 31 an extreme cold front dropped the

temperature several degrees in a few hours and high velocity winds apparently mixed the reservoir. This resulted in an increase in turbidity (23.5 N.T.U.), SRP (60.6  $\mu\text{g/l}$ ) and  $\text{NH}_3\text{-N}$  (153.0  $\mu\text{g/l}$ ) below the reservoir relative to values obtained from other months in group I (December, January, February and March). Similarly, a dramatic increase in turbidity in the hypolimnion of the reservoir and the tailwaters was observed after two weeks of stormy weather in summer 1989 (figure 4, appendix 4). The shallow waters of the reservoir, the weak thermal stratification and the limited protection provided by shoreline vegetation clearly favored the mixing action of the wind. Therefore, it appears that the reservoir can mix on any season, over all during fall and winter when the water level at the reservoir tends to be lower than in summer and the water is well mixed.

Spring run-off flows apparently flushed the bottom sediments of the reservoir into the outlet, causing a dramatic increase in nutrients and turbidity downstream the reservoir (see table II). During the summer a slight thermocline was formed in the reservoir and very low values of oxygen were measured in the hypolimnion (particularly at the north station) (figure 4). Stratification generally enhances chemical changes in the outlet (Ridley and Simons, 1972). Indeed, very high concentration of nutrients, particularly  $\text{NH}_3\text{-N}$  and SRP, were measured in the outlet. Moreover, a positive DO gradient occurred from the outlet to the mouth during the summertime. On the other hand, pH (maximum= 9.67) and DO

Figure 4. Vertical profile of specific conductivity, turbidity, pH, dissolved oxygen and temperature in Lower Crow Reservoir (A) during a period of stratification, 17 July 1989; (B) after mixing, 31 August 1989. Figures above correspond to a sampling site located in front of the outlet (Grizzly Station). Figures below correspond to a sampling site located on the north fork of the reservoir (North Station). See appendix 6 to locate sampling sites.



(maximum= 15.65 mg/l) were high in the epilimnion as a result of photosynthetic processes (appendix 5). Blooms of *Mycrocystis* and *Aphanizomenon* were observed in late summer. Inflow to the Lower Crow Reservoir was low in  $\text{NH}_3\text{-N}$ .  $\text{NH}_3\text{-N}$  built up in the hypolimnion under anoxic conditions during the summer and dramatically decreased due to oxidation processes after fall overturn (table II). A similar pattern was observed for SRP.

From May to August there was an increase in temperature, pH, % oxygen saturation, specific conductivity, alkalinity, turbidity, TSS,  $\text{NH}_3\text{-N}$ , TPN, SRP and TP and a decrease in DO and nitrates + nitrites from the pristine waters of Crow Creek Canyon (site 6) to site 5 (table II). All of the above variables were higher in the reservoir outlet except for temperature, pH and % oxygen saturation which decreased. Although a rapid downstream recovery of some of the variables occurred from the outlet to the mouth only pH, % oxygen saturation and  $\text{NH}_3\text{-N}$  (this last one only recovered in July and August) reached similar values to those obtained at site 5. On the other hand, specific conductivity, alkalinity, turbidity and TSS increased from the dam to the Flathead River. POC (particulate organic carbon) and PN (particulate nitrogen) reached their higher values during spring run-off. No general pattern for these two variables was observed, except for exhibiting a marked increase from site 6 to the outlet in May, June and July (values for August were missing).

## Zoobenthos

A total of 65 taxa were collected at the four sites below the reservoir during the study period (table III). Aquatic insects accounted for most of the taxa (86%). Diptera (16 taxa), Trichoptera (13 taxa) and Ephemeroptera (9 taxa) were the groups with highest richness.

*Hydropsyche occidentalis*, *Cheumatopsyche* sp., *Ephemerella inermis*, *Baetis* spl., *Chironomidae*, *Simulium* spp. and *Optioservus* spp. were the most common taxa (in terms of density and biomass) in all sites below the reservoir (table III). Changes over time in biomass of several of these species can be seen in figure 5. Faunal composition at site 5 was more similar to that found at sites 1 and 2 than that at sites 3 and 4. For example, species such as *Brachycentrus* sp., *Argia* sp., *Petrophila* sp., *Oecetis* sp. reappeared in the downstream sections; whereas they were always absent at sites 3 and 4 below the dam. Of the seven taxa found only at site 5, only *Leucotrichia* sp. occurred in significant numbers. It is possible that these species were an important component of the ecotone between the mountain and prairie ecosystems before the degradation of the system by human activities. During preimpoundment conditions, they may have extended downstream to the confluence with the Flathead River. On the other hand, certain species which were very common in site 4 exhibited very low numbers (eg., *Ephemerella inermis*) or were absent (eg., *Atherix* sp.) above the reservoir (May and July). The fauna of North Crow Creek (site 6) was markedly different from that of the other sites (table III, figure 6).

TABLE III. Distribution, abundance and biomass of macroinvertebrates in Crow Creek. Codes were assigned according to average annual values for each taxa. - =not found; R(rare)=<10; C(common)=10-99; A(abundant)=100-499; V(very abundant)=> 500 individuals per m<sup>2</sup>. 0=<40; 1=40-400; 2=400-800; 3=800-1600; 4=> 1600 mg/m<sup>2</sup>. Three digit species codes are shown for selected taxa.

TAXA	ABUNDANCE						BIOMASS					
	SITE						SITE					
	1	2	3	4	5	6	1	2	3	4	5	6
<b>EPHEMEROPTERA</b>												
<i>Baetis</i> sp1. BAE1	V	V	V	V	V	V	2	2	2	1	1	-
<i>Baetis</i> sp2. BAE2	A	C	-	-	-	-	0	0	-	-	-	-
<i>Baetis</i> sp3.	R	-	-	-	-	-	0	-	-	-	-	-
<i>Baetis</i> sp4.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Baetis bicaudatus</i> BAB	-	-	-	-	-	A	-	-	-	-	-	1
<i>Paraleptophlebia</i> sp. PAR	C	A	C	R	C	-	0	0	0	0	0	-
<i>Heptagenia</i> sp. HEP	C	C	C	-	R	-	0	0	0	-	0	-
<i>Nixe?</i> sp. NIX	C	C	R	-	C	-	0	0	0	-	0	-
<i>Epeorus alberta</i>	R	-	-	-	R	-	0	-	-	-	0	-
<i>Epeorus longimanus</i> EPL	-	-	-	-	-	V	-	-	-	-	-	1
<i>Rithrogena robusta</i> RHR	-	-	-	-	-	C	-	-	-	-	-	0
<i>Cinygmula</i> sp. CIN	-	-	-	-	-	V	-	-	-	-	-	1
<i>Ephemerella inermis</i> EPH	V	V	V	V	C	-	1	1	2	4	0	-
<i>Drunella grandis</i> DRU	-	-	-	-	-	C	-	-	-	-	-	0
<i>Drunella doddsi</i> DRD	-	-	-	-	-	C	-	-	-	-	-	1
<i>Drunella</i> A sp. DRU	-	-	-	-	-	C	-	-	-	-	-	0
<i>Caudatella</i> sp.	-	-	-	-	-	C	-	-	-	-	-	0
<i>Tricorythodes</i> sp. TRI	C	C	R	A	R	-	0	0	0	1	0	-
<i>Ameletus</i> sp.	-	-	-	-	-	C	-	-	-	-	-	0
<b>TRICHOPTERA</b>												
<i>Cheumatopsyche</i> sp. CHE	V	A	V	A	A	-	3	1	3	1	1	-
<i>Hydropsyche cockerelli</i> HCO	A	R	R	R	A	-	1	0	0	0	1	-
<i>H. occidentalis</i> HOC	V	V	V	V	V	-	3	3	4	4	3	-
<i>Parapsyche elsis</i> sp. PAR	-	-	-	-	-	R	-	-	-	-	-	1
<i>Dicosmoecus</i> sp. DIC	C	R	C	C	R	-	2	1	3	1	0	-
<i>Onocosmoecus</i> sp. ONO	R	-	R	R	R	-	0	-	1	0	0	-
<i>Neophylax</i> sp1. NEO	-	R	C	R	R	-	-	0	0	0	0	-
<i>Neophylax</i> sp2.	-	-	-	-	-	C	-	-	-	-	-	0
<i>Chyranda</i> sp.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Limnephilidae</i> sp1.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Limnephilidae</i> sp2.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Oecetis</i> sp. OEC	A	A	R	-	C	-	0	0	0	-	0	-
<i>Ceraclea</i> sp.	-	-	-	-	R	-	-	-	-	-	0	-
<i>Lepidostoma</i> sp.	-	-	-	-	R	-	-	-	-	-	0	-
<i>Hydroptila</i> sp. HDT	C	R	R	R	-	-	0	0	0	0	-	-
<i>Leucotrichia</i> sp.	-	-	-	-	C	-	-	-	-	-	0	-
<i>Brachycentrus</i> sp. BRA	C	A	R	-	A	-	0	1	0	-	1	-
<i>Micrasema</i> sp.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Glossosoma</i> sp.	R	C	C	R	C	-	0	0	0	0	0	-

TABLE III. Continued

<i>Protophila</i> sp. PTT	-	R	-	-	-	-	-	0	-	-	-	-
<i>Anagapetus</i> sp.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Psychomyia</i> sp. PSY	R	R	-	-	-	-	0	0	-	-	-	-
<i>Rhyacophilidae</i> sp.	-	-	-	-	R	-	-	-	-	-	0	-
<i>Rhyacophila acropedes</i>	-	-	-	-	-	C	-	-	-	-	-	0
<i>R. verrula</i>	-	-	-	-	-	C	-	-	-	-	-	0
<i>R. vaccua</i>	-	-	-	-	-	C	-	-	-	-	-	0
<i>R. narvae?</i>	-	-	-	-	-	R	-	-	-	-	-	0
<i>R. hyalinata?</i>	-	-	-	-	-	R	-	-	-	-	-	0
<i>R. alberta?</i>	-	-	-	-	-	R	-	-	-	-	-	0
<i>Helicopsyche</i> sp. HEL	C	C	A	R	C	-	0	0	0	0	0	-

## PLECOPTERA

<i>Pteronarcys californica</i>	-	R	R	-	-	-	-	0	0	-	-	-
<i>Zapada cinctipes</i> ZAP	C	A	C	C	-	-	0	1	0	0	-	-
<i>Z. columbiana</i>	-	-	-	-	-	C	-	-	-	-	-	0
<i>Visoka</i> sp.	-	-	-	-	-	C	-	-	-	-	-	0
<i>Capnia</i> sp.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Leuctridae</i> sp.	-	-	-	-	-	C	-	-	-	-	-	0
<i>Claassenia sabulosa</i> CLA	C	C	R	R	C	-	1	1	1	0	2	-
<i>Hesperoperla pacifica</i> HES	R	R	R	R	-	-	1	1	1	0	-	-
<i>Chloroperlidae</i> sp.	-	-	-	R	-	-	-	-	-	0	0	0
<i>Paraperla</i> sp.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Sweltsa</i> spp. SWE	-	-	-	-	-	A	-	-	-	-	-	0
<i>Alloperla</i> spp.	-	-	-	-	-	C	-	-	-	-	-	0
<i>Isoperla</i> sp.	C	R	-	-	-	-	0	0	-	-	-	-
<i>Skwala parallela</i> SKW	R	C	R	-	C	-	1	1	0	-	0	-
<i>Megarcys watertoni</i>	-	-	-	-	-	R	-	-	-	-	-	1
<i>Isogenoides</i> sp.	-	-	-	-	-	C	-	-	-	-	-	0
<i>Yoraperla brevis</i>	-	-	-	-	-	R	-	-	-	-	-	0

## DIPTERA

<i>Tipula</i> sp. TIP	R	R	R	R	-	-	2	0	1	1	-	-
<i>Antocha</i> sp. ANT	R	R	R	-	C	-	0	0	0	-	0	-
<i>Dicranota</i> spp.? DCR	C	C	C	R	C	C	0	0	0	0	0	0
<i>Hexatoma</i> sp.	R	R	-	-	-	-	0	0	-	-	-	-
<i>Agathon</i> sp.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Dixidae</i> sp.	-	R	-	-	-	-	-	0	-	-	-	-
<i>Simulium</i> spp. SIM	V	V	V	V	V	C	2	2	1	1	1	0
<i>Prosimulium</i> sp.	-	-	-	-	-	C	-	-	-	-	-	0
<i>Ceratopogonidae</i> sp. CER	C	C	R	R	C	-	0	0	0	0	0	-
<i>Chironomidae</i> CHIR	V	V	V	V	V	V	2	2	2	2	1	1
<i>Pericoma</i> sp.	R	R	-	R	-	-	0	0	-	0	-	-
<i>Psychoda?</i> sp.	-	-	-	-	R	-	-	-	-	-	0	-
<i>Stratiomyidae</i> sp.	R	-	-	-	-	-	0	-	-	-	-	-
<i>Tabanidae</i> sp.	-	R	-	-	-	-	-	0	-	-	-	-
<i>Atherix</i> sp. ATH	-	C	R	A	-	-	-	1	1	2	-	-
<i>Glutops</i> sp.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Chelifera</i> sp. CLF	R	R	-	C	-	-	0	0	-	0	-	-
<i>Hemerodromia</i> sp. HEM	A	A	C	A	C	-	0	0	0	0	0	-
<i>Oreogeton</i> sp.	-	-	-	-	-	R	-	-	-	-	-	0
<i>Ephydriidae</i> sp.	R	-	-	-	-	-	0	-	-	-	-	-
<i>Limnophora</i> sp.	R	R	-	-	-	-	0	0	-	-	-	-

TABLE III. Continued.

## COLEOPTERA

<i>Optioservus</i> spp. OPT	V	V	V	V	V	-	1	1	1	0	1	-
<i>Zaitzevia parvula</i> ZAI	V	V	V	R	V	V	1	1	1	0	1	-
<i>Lara avara</i>	-	-	-	-	R	-	-	-	-	-	0	-
<i>Dubiraphia vittata</i>	R	-	-	-	-	-	0	-	-	-	-	-
<i>Heterlimnius corpulentus</i>	-	-	-	-	-	C	-	-	-	-	-	0
<i>Octhebius</i> sp.	-	-	-	R	-	-	-	-	-	0	-	-
<i>Hydrophilidae</i> sp.	-	-	-	-	R	-	-	-	-	-	0	-
<i>Hydaticus?</i> sp.	-	-	R	-	-	-	-	-	0	-	-	-
<i>Helichus striatus</i>	R	-	-	-	-	-	0	-	-	-	-	-

## ODONATA

<i>Argia</i> sp. ARG	C	C	R	-	R	-	0	0	0	-	0	-
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## LEPIDOPTERA

<i>Petrophila</i> sp. PET	C	C	R	-	C	-	1	0	0	-	0	-
---------------------------	---	---	---	---	---	---	---	---	---	---	---	---

## MEGALOPTERA

<i>Sialis</i> sp.	R	-	-	R	-	-	0	-	-	0	-	-
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## OLIGOCHAETA OLI

<i>HIRUDINEA</i>	V	V	V	V	C	C	1	1	1	1	1	0
------------------	---	---	---	---	---	---	---	---	---	---	---	---

## ARACHNIDA

<i>Hydracarina</i> spp1. HDC	A	C	C	R	C	-	0	0	0	0	0	-
<i>Hydracarina</i> spp2.	-	-	-	-	-	C	-	-	-	-	-	0

## TRICLADIDA

<i>Dugesia tigrina</i> DUG	A	A	C	A	C	-	1	0	0	1	0	-
<i>Planariidae</i> sp.	-	-	-	-	-	R	-	-	-	-	-	0

## MOLLUSCA

<i>Physa</i> sp. PHY	C	A	R	R	-	-	0	0	0	0	-	-
<i>Limnaea</i> sp. LMN	-	R	C	C	-	-	-	0	1	1	-	-
<i>Planorbidae</i> sp.	-	R	-	-	-	-	-	0	-	-	-	-
<i>Ancylus</i> sp.	R	R	-	-	-	-	0	0	-	-	-	-
<i>Sphaeridae</i> sp.	R	R	R	-	-	-	0	0	0	-	-	-

## CRUSTACEA

<i>Ostracoda</i> OST	C	C	C	C	-	C	0	0	0	0	-	0
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## AMPHIPODA

<i>Gammarus</i> sp. GAM	C	C	C	C	R	-	0	0	0	0	0	-
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Figure 5. Changes in average biomass over time of selected taxa for a the study sites. Taxa codes are shown in appendix 1. A)=site 1; B)= si 2; C)= site 3; D)=site 4 E)=site 5; F)=site 6. Taxa plotted for site 6 were the most important in terms of biomass at that site. Notice the change in scale among the different figures. The legends in graphs A a B apply to graphs A-E. The legends in graph F apply only to F.

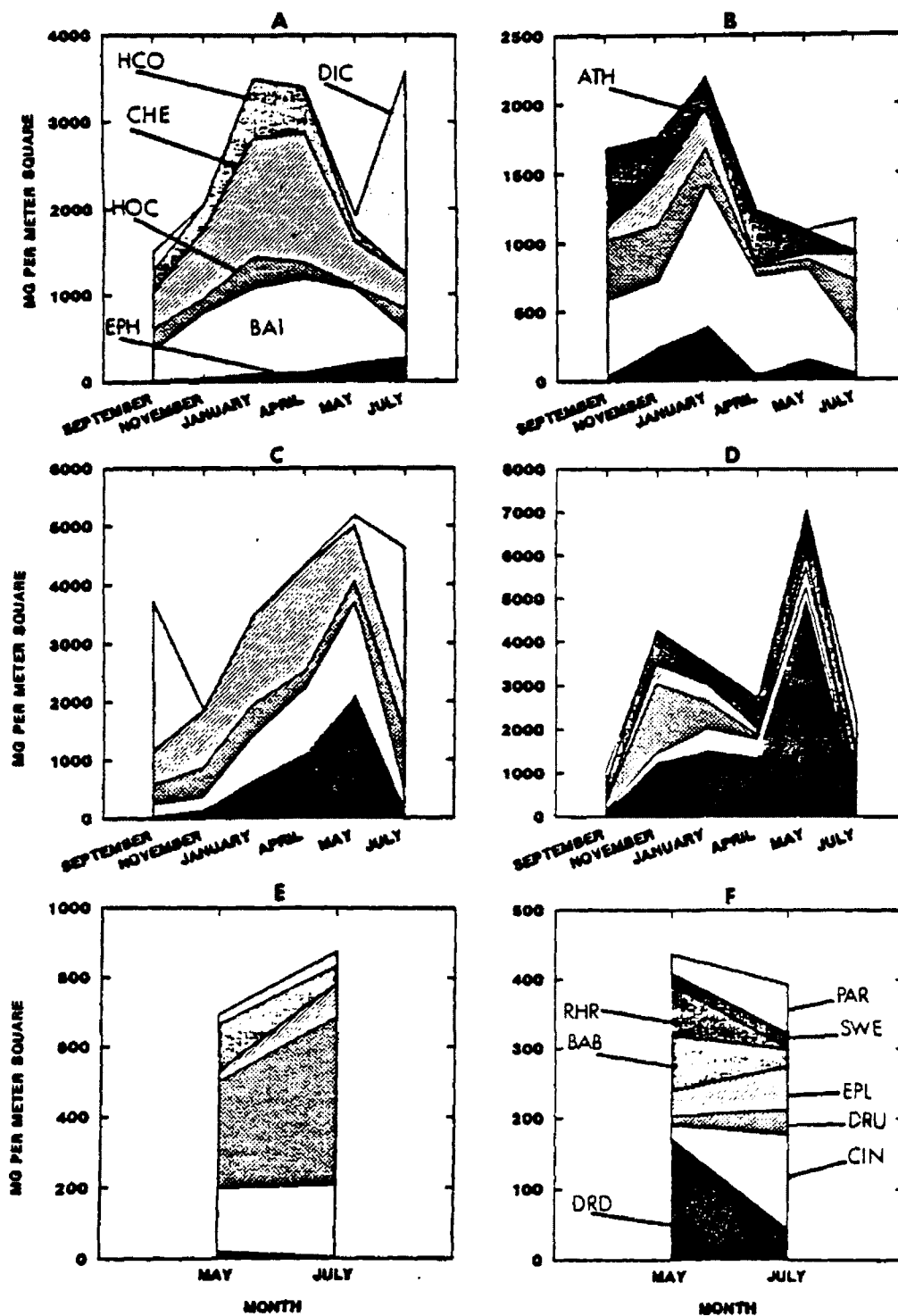
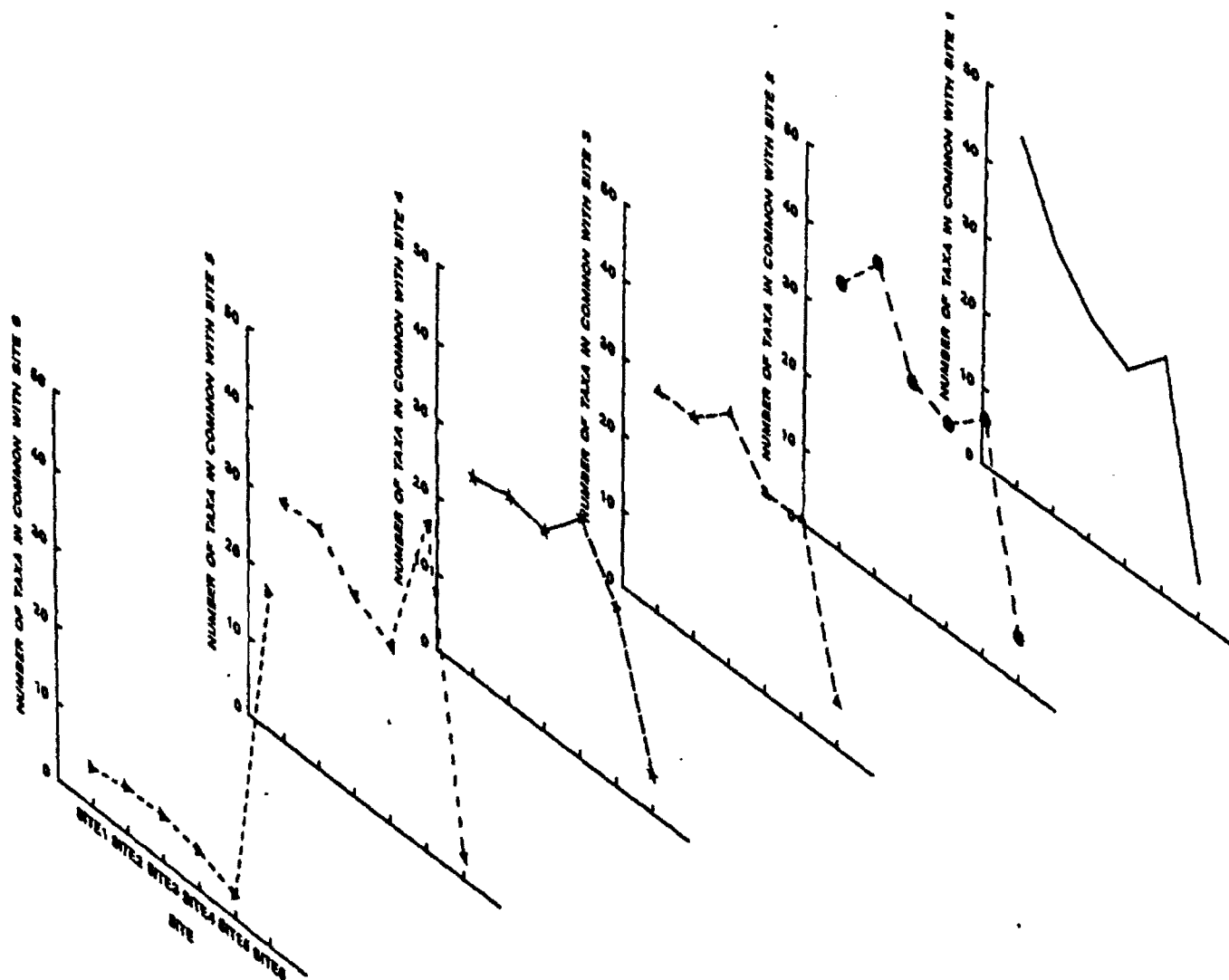


Figure 6. Taxa composition similarities for the different sites. Each line represents the number of taxa occurring in that site and the number of taxa that site shares with the other sites. Taxa belong to composite samples from May and July 1989.



Number of taxa of Ephemeroptera, Trichoptera and Plecoptera slightly increased at site 6 relative to downstream sites while number of Coleoptera and Diptera taxa decreased (table III). Richness, densities and biomass of non insect taxa were lower at site 6 than in downstream sites.

Below the reservoir, richness was always higher at sites 1 and 2 and generally increased in a downstream direction (table IV). Site 2 showed the highest oscillations in species numbers over time. Number of species lost between two sampling dates was particularly noticeable between January and April, and May and July (table IV). Temporal and longitudinal dynamics of evenness and diversity did not always agree when compared in terms of biomass and density. Moreover, biomass evenness and biomass diversity values were generally higher than density evenness and density diversity. No general patterns over time were observed although density evenness tended to be lower in May and July.

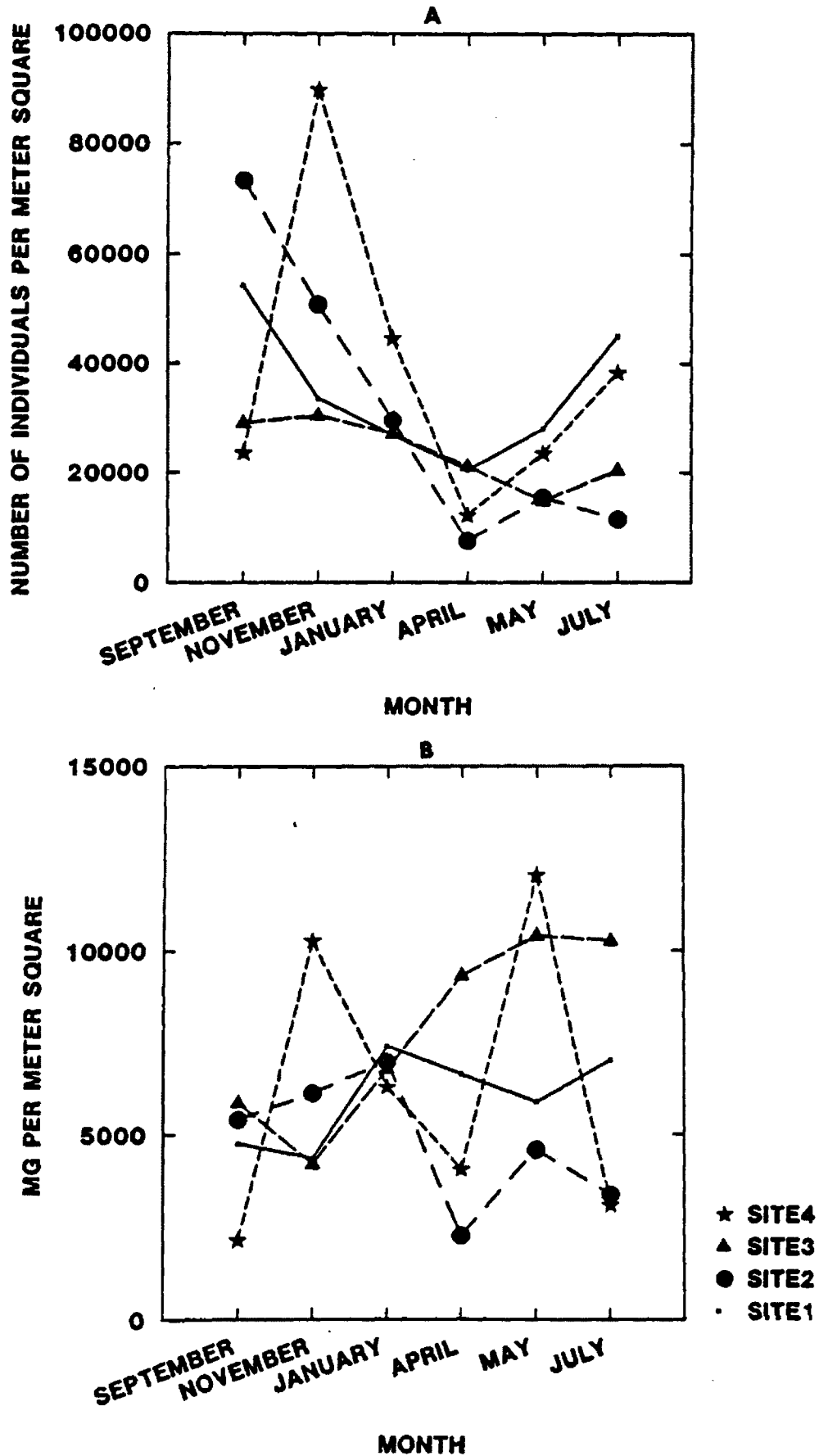
On an annual basis (taking all samples per site together), biomass evenness and  $H'$  increased from the reservoir to the mouth. Again, different patterns were observed when density units were used. Increase in number of taxa seemed to level off at site 2 (54 taxa). Changes in taxa composition from the reservoir to the mouth can generally be explained in terms of species additions from site to site (figure 6).

The standing crop in regulated waters may be enhanced or reduced compared to unregulated sections (Ward & Stanford, 1979). Mean densities at sites 5 and 6 were in the the same range as those of the regulated

TABLE IV. Longitudinal and temporal changes in richness, diversity ( $H'$ ) and evenness.  $H'$  and evenness were calculated using density and biomass units (in parenthesis). Turnover refers to numbers of taxa gained and lost between two sampling dates.

	SEPTEMBER	NOVEMBER	JANUARY	APRIL	MAY	JULY	ALL SAMPLES
SITE1	RICHNESS	42	35	35	36	38	54
	EVENNESS	0.592	0.529	0.554	0.576	0.323	0.492
		(0.716)	(0.677)	(0.666)	(0.662)	(0.573)	(0.674)
	$H'$	2.214	1.882	1.968	2.065	1.174	1.963
		(2.677)	(2.407)	(2.369)	(2.373)	(2.083)	(2.688)
	TURNOVER		-9 +2	-4 +4	-6 +7	-4 +6	-12 +7
SITE2	RICHNESS	37	35	40	29	35	54
	EVENNESS	0.575	0.588	0.525	0.478	0.399	0.533
		(0.658)	(0.725)	(0.626)	(0.578)	(0.504)	(0.649)
	$H'$	2.077	2.091	1.938	1.611	1.418	2.127
		(2.377)	(2.578)	(2.308)	(1.947)	(1.794)	(2.587)
	TURNOVER		-5 +3	-4 +9	-16 +5	-6 +12	-11 +7
SITE3	RICHNESS	32	29	33	29	28	44
	EVENNESS	0.589	0.589	0.595	0.574	0.546	0.536
		(0.528)	(0.532)	(0.605)	(0.633)	(0.695)	(0.638)
	$H'$	2.042	1.983	2.082	1.933	1.819	2.027
		(1.829)	(1.791)	(2.115)	(2.132)	(2.315)	(2.414)
	TURNOVER		-7 +4	-3 +7	-7 +3	-5 +4	-6 +5
SITE4	RICHNESS	26	26	26	20	29	38
	EVENNESS	0.516	0.429	0.417	0.490	0.392	0.432
		(0.670)	(0.450)	(0.582)	(0.615)	(0.532)	(0.559)
	$H'$	1.680	1.397	1.358	1.467	1.319	1.570
		(2.182)	(1.465)	(1.895)	(1.843)	(1.793)	(2.034)
	TURNOVER		-6 +6	-4 +4	-10 +4	-2 +11	-7 +2
SITE5	RICHNESS	-	-	-	-	32	38
	EVENNESS	-	-	-	-	0.577	0.432
		-	-	-	-	(0.592)	(0.558)
	$H'$	-	-	-	-	2.000	1.570
		-	-	-	-	(2.053)	(2.031)
	TURNOVER	-	-	-	-		-3 +9
SITE6	RICHNESS	-	-	-	-	40	37
	EVENNESS	-	-	-	-	0.241	0.546
		-	-	-	-	(0.689)	(0.767)
	$H'$	-	-	-	-	0.883	1.973
		-	-	-	-	(2.524)	(2.769)
	TURNOVER	-	-	-	-		-8 +5

Figure 7. Average number (A) and biomass (B) of macroinvertebrates at four sites (1, 2, 3 and 4) for the six sampling dates.



sites (figure 7a) in May (9140.0 and 14010.7 ind./m<sup>2</sup> for sites 5 and 6 respectively). In July only site 5 (46532.0 ind./m<sup>2</sup>) was in the same range (site 6, 4198.7 ind./m<sup>2</sup>). On the other hand, biomass clearly was lower at sites 6 and 5 compared to the regulated sites (compare with values in figure 7b). Thus, average biomass in May was 798.9 and 3146.4 mg/m<sup>2</sup> for sites 6 and 5 respectively. The same trend was registered in July (666.7 and 3854.4 mg/m<sup>2</sup> for sites 6 and 5 respectively). This longitudinal increase in biomass was strongly correlated with conductivity ( $r = 0.79$ ,  $p < 0.001$ ) and total alkalinity ( $r = 0.77$ ,  $p < 0.001$ ) (table 5). A similar relationship was found by Winget (1985) who related this trend to the importance of alkalinity in primary production, especially under very low carbon dioxide concentrations. It appears that the trophic status of the reservoir influences community structure in the tailwaters (eg., see Perry & Sheldon, 1986 for lake outlet communities).

The Crow Creek system has been negatively affected over the years by fluctuating flows (both regulated and diverted for irrigation), bank erosion and grazing. However, the creek appears to retain many of its original ecological attributes in its lower reaches, assuming the reaches above the reservoir are indicative of predisturbance conditions. Although the influence from the reservoir was still evident in downstream reaches, conditions at the mouth, as reflected from the recovery (resetting) in some biological and physical variables, might not have been very different from those found before impoundment. Seasonal and diurnal temperature oscillations, which are factors

directly related to biotic diversity (Stanford & Ward, 1983; Vannote et al., 1980), greatly increased in a downstream direction. Furthermore, species richness generally increased along the gradient from the reservoir to the mouth where it reached values similar to those found in the pristine waters of North Crow Creek (May and July) (see figure 6). In May, the number of species collected at the mouth was even higher than that found right above the reservoir. Another sign of recovery comes from the significant downstream increase on an annual basis of  $H'$  and evenness (based on biomass units).

The occurrence of warm water species below the reservoir as *Cheumatopsyche* sp., *Helicopsyche* sp., *Petrophila* sp., *Tricorythodes* sp., and *Argia* sp. may indicate that a remnant fauna of the Palouse Prairie ecosystem still exists in the creek. The regulated segment also included cold water species (eg., the stoneflies *Zapada cinctipes*, *Skwala parallela* and *Claassenia sabulosa*) which are common in many other habitats in the basin. The presence of *Skwala parallela* and *Claassenia sabulosa* above the reservoir in May and July suggest that these species probably occurred in the creek before impoundment. Regulation has produced marked changes in community structure below the reservoir through changes in the temperature regime (eg., less diurnal oscillation, cooler summer and warmer winter conditions), altered hydrograph and a dramatic increase in nutrient concentrations. The substrate in sites 4 and 3 is heavily covered with moss and algae. *Ephemerella inermis*, a univoltine species well known to increase numbers and biomass in response to algal and moss growth (Spence and Hynes,

1971; Zimmermann and Ward, 1984) reached maximum densities and biomasses below the reservoir (figure 5). A similar pattern has been reported by Stanford & Ward (1990). This species has also been associated with slow current velocities (Minshall & Minshall, 1977; Sheldon and Haick, 1981). Shelter from the current and food supply provided by the moss and algae could together explain its high numbers and biomass in site 4. Biomass and density of predators such as *Dugesia tigrina* and *Atherix* sp. were enhanced below the reservoir. Larvae of *Atherix* sp., are commonly associated with aquatic vegetation and feed on the larvae of *Chironomidae* and nymphs of Ephemeroptera (Webb, 1981). Increases in algal and moss growth below the dam and life cycle strategies not suited to regulated environments appear to be the cause of the absence of heptagenids in site 4 (Brittain & Salveit, 1989). Downstream shift of *Hydropsyche cockerelli* has also been reported in a regulated segment of the Flathead River by Hauer and Stanford (1982b). However, in this study *Hydropsyche occidentalis* occurred in higher densities and biomass in the sites more affected by regulation, while in the above study the opposite pattern for the same species was observed. It appears that much less dramatic changes in flow and temperature and possible differences in food quantity and quality in Crow Creek relative to that regulated segment of the Flathead River may account for this pattern. The bimodal distribution of *Cheumatopsyche* sp. (table III, figure 5) may be related to the much higher percentage of boulders in sites 1 and 3 (see appendix 2). However, Wallace (1975) reported larvae of *Cheumatopsyche* and *Hydropsyche* occurring almost exclusively on the upper surface of



cobbles. Miller (1985) found that patterns in abundance of the same genus were related to differences among sites in water depth but no depth measurements were taken in this study.

## Fish

A major drawback in this study was the high turbidity of the water. This was especially true during the fall. In spring although the water was relatively clear, it became turbid once the silt-laden substrata was disturbed. For this reason, it was very difficult to collect small fish and population estimates could not be made in many cases. On the other hand, spring sampling coincided with the spawning migration into the creek of at least one species of fish (Largescale Sucker) what probably caused a biased estimate.

A total of 10 species was collected below the reservoir during the two annual surveys (appendix 6). As mentioned above rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) population estimates were reported elsewhere; therefore, only the most significant trends are documented here. Basically, the species composition was the same for both seasons. Juvenile largescale suckers (*Catostomus macrocheilus*) and yellow perch (*Perca flavescens*) obtained highest densities in the fall, particularly in section 3. A similar trend was observed for northern squawfish (*Ptychocheilus oregonensis*) and redbside shiner (*Richardsonius balteatus*) although they were collected in higher numbers in site 1. On the other hand, the latter species were never collected in site 4. Among fish other than trout, largescale suckers

were the dominant fish below the reservoir particularly in site 1 where the highest population estimate was 1942 individuals per km meters (spring 1989). The few specimens of largemouth bass (*Micropterus salmoides*) and Black bullhead (*Ictalurus melas*) collected in the creek apparently came from the reservoir. The same thing applies for many individuals of Yellow perch.

A common pattern observed in both spring and fall was the opposite distribution of trout and non game fish. Below the reservoir, trout numbers increased in an upstream direction (Ringo and Halfmoon, 1990) while in general non game fish numbers and biomass increased downstream. Trout distribution appeared to follow the same pattern before the stocking program started (Cross *et al*, 1989). Low trout numbers in the lower reaches may be related to the fact that high numbers of nongame fish, particularly suckers, inhabit or use that section. However, nothing can be concluded about the non game fish distribution. Several beaver dams occurred between site 3 and site 1. Wild rainbow and brown trout collected in the upper sections suggested that the dams were not a total barrier for them, but their interactions with species like suckers is unknown. Although is interesting to mention that the higher recruitment of suckers was observed in site 3 above the dams (see appendix 5).

The low success of the stocking program to date suggests the creek lacks suitable conditions to support a trout population. Only 1.1% of the marked rainbow trout planted in 1988 were recaptured in the spring of 1989 (Ringo & Halfmoon, 1990). Similar results were obtained in the

spring of 1990. Benthos standing stocks seemed high enough to support an abundant fish community. For instance, the hydropsychid caddisflies, which were the dominant macroinvertebrates found in fish gut contents in the creek, averaged 688 ind./m<sup>2</sup> in the Lower Flathead River (Hauer and Stanford, 1990), while in Crow Creek averaged 3285 ind./m<sup>2</sup>. Moreover, the water parameters analyzed were below the critical levels recommended by EPA (EPA, 1985). However, sometimes the combined action of different factors can cause disruptions of the fauna in tailwater environments (Edwards, 1978). Furthermore, the creek is under considerable stress: high turbidity water enter the tailwaters after the reservoir mixes (which seems to happen at any time during the year) or as surface run-off from irrigated farmlands, clogging the interstice spaces in the substrata and accumulating in the aquatic vegetation. The immediate result is a slow deterioration of the spawning gravel quality in the creek.

Stanford (1990) pointed out the necessity of solving water quality and other habitat (e.g., temperature) problems before using mitigation technics such as augmentation of a damaged fishery with hatchery stocks. Effects of turbidity, changes in flow and temperature regime (seasonal and diel) and other environmental variables on trout distribution and population dynamics are unknown in Crow Creek. The current sampling regime does not allow one making inferences about changes in trout populations in short periods of time in response to environmental changes. A possible approach could be the use of radio tags to follow the fish of different year classes (wild and hatchery trout) to study

their response to different environmental conditions. This kind of information put into a holistic perspective might lead to new strategies to enhance the trout recovery in the Lower Flathead.

### Principal Components Analysis

A Principal Components analysis of the transformed chemical variables summarized longitudinal and seasonal tendencies of the water chemistry below Lower Crow Reservoir during the study period (see table II and figure 8). The first three principal components accounted for the 74.7 % of the total variance. Five group of samples corresponding to different months were extracted from the ordination resulting from the first two principal components: group I (December, January, February, March), group III (April), group II (October and November), group IV (May, June) and group V (July, August and September).

The first principal component (43.0 % of the total variance) reflected the seasonal variation in water chemistry variables. This first component was positively correlated with temperature ( $p < 0.001$ ), SRP ( $p < 0.001$ ), discharge ( $p < 0.01$ ) and  $\text{NH}_3\text{-N}$  ( $p < 0.05$ ) and negatively correlated with specific conductivity ( $p < 0.001$ ), alkalinity ( $p < 0.001$ ), DO ( $p < 0.001$ ) and nitrate + nitrite ( $p < 0.001$ ) (table V). Temperature, SRP, discharge and  $\text{NH}_3\text{-N}$  were relatively higher in the period April-September while DO, specific conductivity, alkalinity and nitrates + nitrites were relatively lower. The opposite pattern was observed for the time period October-March. The second principal component (20.80 % of the total variance) represented the chemical gradient from the

Figure 8. Principal Components Analysis (PCA) of 11 physical and chemical variables (Temperature, pH, DO, % Oxygen saturation, specific conductivity, alkalinity, turbidity, discharge,  $\text{NH}_3\text{-N}$ , nitrate + nitrite and SRP) for sites 1, 2, 3 and 4 corresponding to a total of 48 samples taken monthly during the study period. Site symbols same as figure 3.

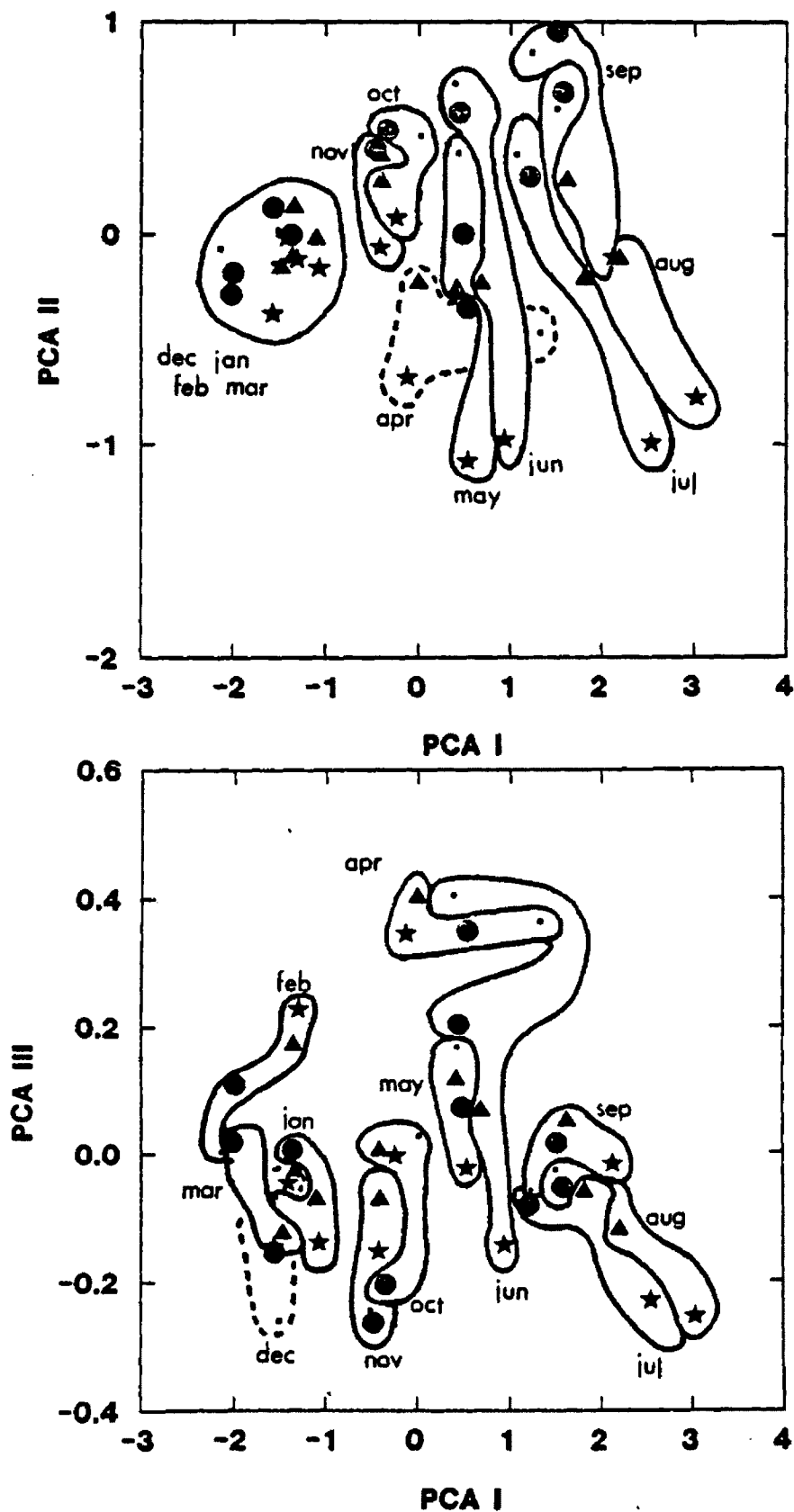


TABLE V. (A) Pearson correlations coefficients between physical and chemical variables and the first three principal components (two tailed test).  $r = .371$  significant at the 1% level;  $r \geq .387$  sig. at the 0.1% level ( $n=48$ ). (B) Pearson correlation coefficients between DCA scores and environmental variables (two tailed test). B=biomass;  $D = \log(\text{density}+1)$  and  $p/a = \text{presence/absence}$ .  $.307-.35$  sig at the 1% level;  $\geq .420$  sig. at the 0.1% level ( $n=72$ ). Two sets of principal components were correlated to the DCA scores: one corresponding to temperature, discharge and chemical variables (same as (A)) and the other (in parenthesis) including in addition the substrata. All the variables were transformed to approximate normality.

	(A)			(B)				
	PCA1	PCA2	PCA3	DCA1	DCA2	DCA3	DCA1	DCA1
				(B)	(B)	(B)	(D)	(p/a)
Temperature	.865	-	-	.468	-	-	-	-
pH	-	.857	-	-	.350	-	-.546	-.670
DO	-.884	-	-	-.586	-	-	-	-
%O <sub>2</sub> sat.	-	.597	.387	-	-	-	-	-
Conductivity	-.920	-	-	-.659	-	-	-	-
Alkalinity	-.917	-	-	-	-	-.420	-	-
Turbidity	-	-	.503	-	-	-	-	-
Discharge	.371	-.635	-	-	-	-	.573	.585
NH <sub>3</sub> -N	-	-.737	.511	-.330	-	.553	.471	.619
NO <sub>2</sub> /3	-.875	-	-	-.477	-	-	-	-
SRP	.669	-	.497	-	-	.337	-	-
Boulder				-	-.307	-	-	-
Cobble				-	.589	-	.313	-
Pebble				-	-	-	-.638	-.558
Gravel				-	-	-	.306	.333
Sand				-	-.438	-	.555	.504
PCA1				0.59	-	-		
				(-0.68)	-	-		
PCA2				-	-	0.62		
				-	(0.49)	(-0.50)		
PCA3				-	-0.82	-		
				-	-	(-0.42)		

reservoir to the mouth. The variables positively correlated with this component were pH ( $p < 0.001$ ) and % oxygen saturation ( $p < 0.001$ ). Discharge ( $p < 0.001$ ),  $\text{NH}_3\text{-N}$  ( $p < 0.001$ ) and SRP ( $p < 0.05$ ) showed a negative correlation with this component. The gradient between the reservoir and the mouth for each month is proportional to the distance between mouth and reservoir samples. On this basis, the most obvious gradients in water chemistry below the reservoir occurred during the months of May, June, July, August and September coinciding with the irrigation season and associated high volume releases from the reservoir (figure 8g). The third principal component (10.9 % of the total variance) correlated the most with samples with relative high values of turbidity, SRP and  $\text{NH}_3\text{-N}$ . Thus the analysis distinguished the samples corresponding to April (spring run-off peak) and samples taken after reservoir turned over in February (see table II and fig. 8b).

#### Detrended Correspondence Analysis

A Detrended Correspondence Analysis (DECORANA) (figure 9a) performed on the taxa biomass summarized community structure in terms of seasonal changes (axis I, eigenvalue= 0.41) and longitudinal changes (axis II, eigenvalue= 0.23). Axis III (eigenvalue= 0.17) appears to relate to the general tendency of most of the dominant taxa to reach their lowest biomass in April or May.

Figure 9. A-F. DECORANA ordination of species in samples space and samples in species space using biomass (A-B), log (density+1) (C-D) and presence/absence (E-F). Species codes appear in table 3. Months are identified by the following symbols: S= September; N= November; R=January; A= April; M= May; J= July. Only taxa significantly correlated ( $p < 0.01$ ) with the axes are shown in the table. \*= outlier.

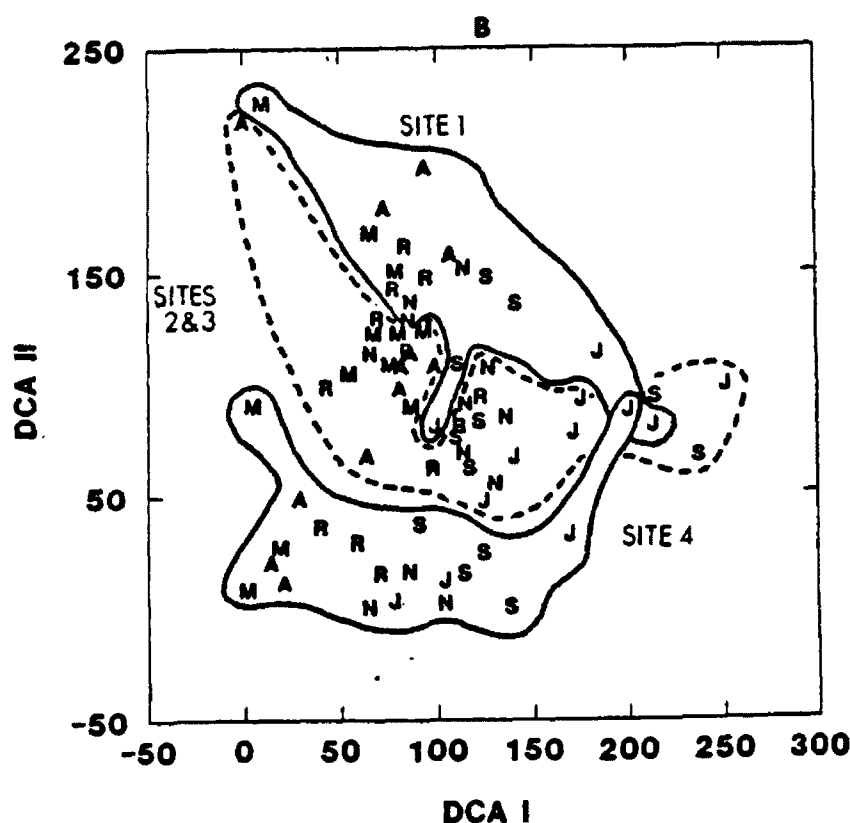
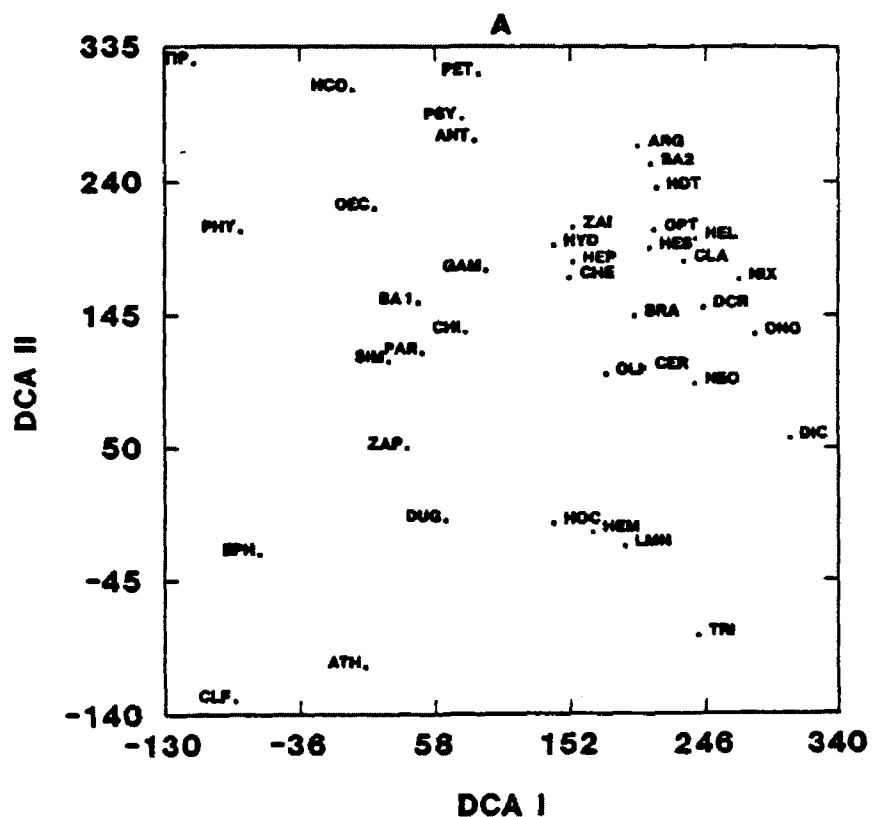




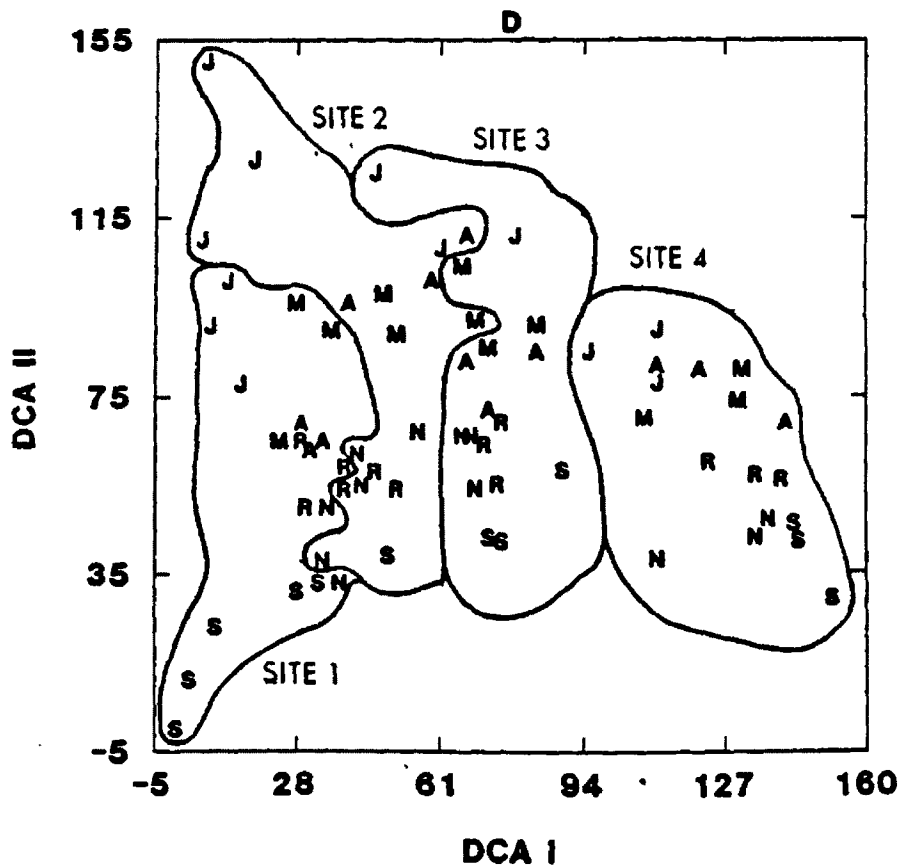
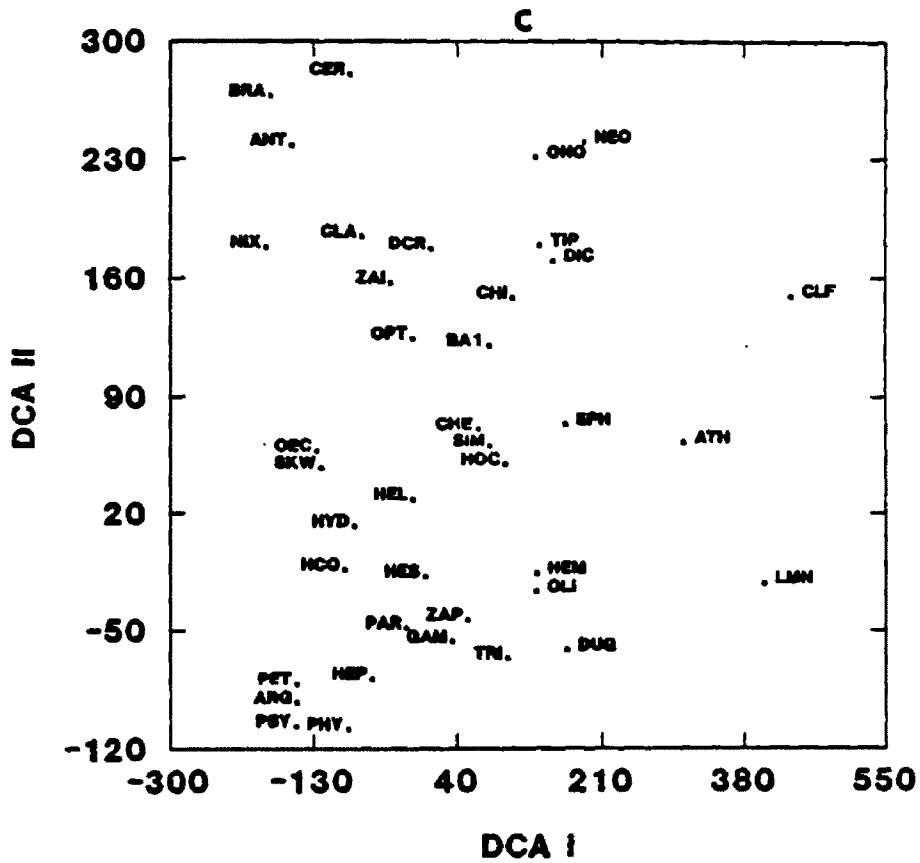
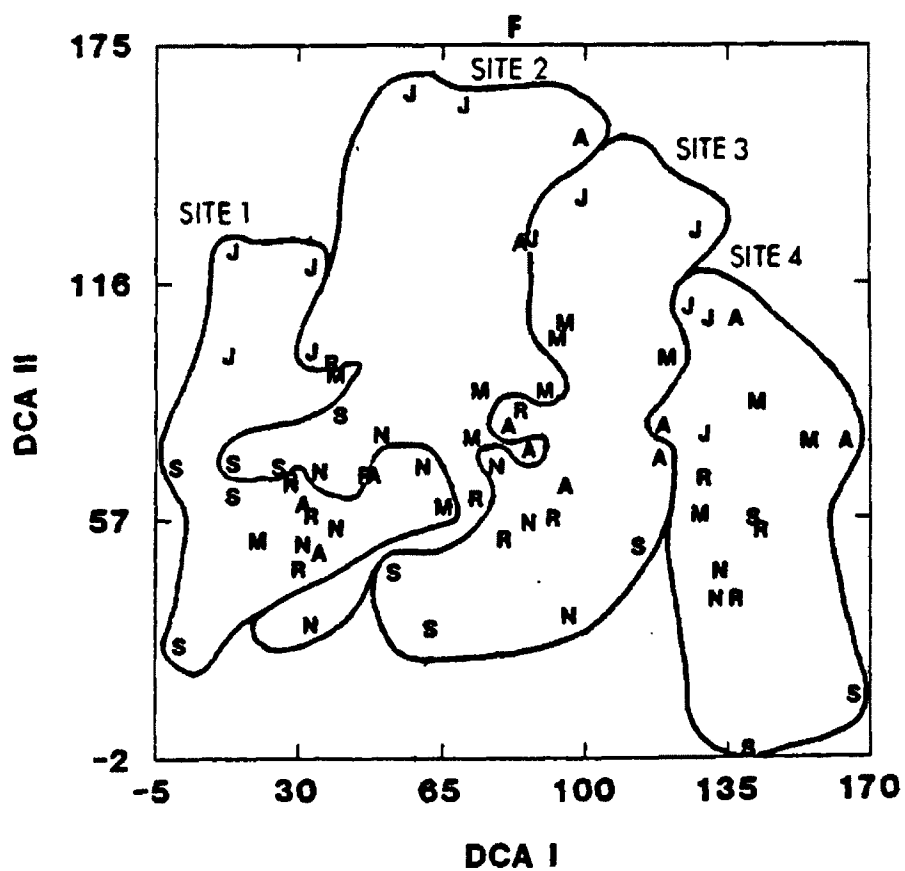
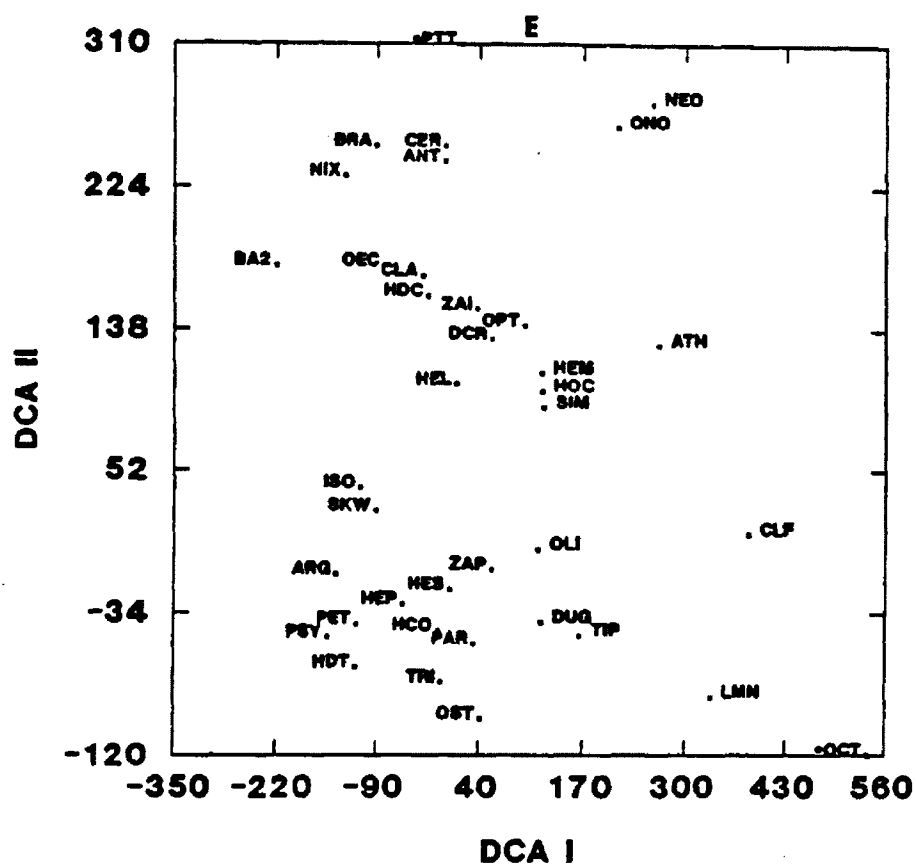
Figure 9. continued.

Figure 9. continued.

The first ordination axis loaded positively on species whose biomass increased to a peak in July or September and negatively on taxa which peaked in May (figure 9a, see also figure 5)). Examples of the first one (from higher to lower correlation with the first axis ( $p < 0.01$ )) were *Dicosmoecus* sp., *Nixe?* sp., *Onocosmoecus* sp., *Dicranota* sp. and *Claassenia sabulosa*. Taxa negatively correlated with this axis ( $p < 0.01$ ) were *Ephemerella inermis*, *Tipula* sp., *Atherix* sp. and *Chelifera* sp. The second ordination axis loaded positively on species which occurred mainly at the mouth like *Petrophila* sp., *Hydropsyche cockerelli*, *Psychomyia* sp. *Tipula* sp., *Antocha* sp. and *Zaitzevia parvula* and negatively on species which occurred mainly close to the reservoir like *Atherix* sp., *Hemerodromia* sp., *Chelifera* sp., and *Tricorythodes* sp. (figure 9a, see also figure 5). Species appearing close to the centre of figure 9a were ubiquitous (eg; *Baetis* sp1 and *Chironomidae*) or showed very low correlations with the first ordination axis (eg; *Gammarus* sp. and *Cheumatopsyche* sp.). The samples ordination (figure 9 b) separated samples from site 1 from those of site 4. samples from sites 2 and 3 appeared in between showing considerable overlap. A clear temporal sequence can be seen in samples from all sites.

Ordinations resulting from presence and absence and log (density+1) revealed similar differences in the fauna among sites (figure 8 c-f). Axis 1 ( eigenvalues = 0.17 and 0.14 for p/a and log (density+1) respectively) reflected the longitudinal gradient from the reservoir to the mouth and axis 2 (eigenvalues= 0.10 and 0.08

respectively) the transition in community structure over time. In the density ordination, faunal temporal changes were more marked in sites 1 and 2 as evidenced by segregation of samples by months. Some overlap occurred between samples from these two sites during the months of September, November and January. Samples from site 3 clearly separated from all of those from site 4 and some overlap occurred with site 2 in April and May. The presence and absence ordination showed similar results although the degree in overlap between sites increased, especially between site 1 and site 2 (particularly in September and November). Samples from site 1 for November, January, April and May appeared very cluttered. Temporal trends are specially clear in site 3 and in minor degree in site 4, and diffuse in sites 1 and 2. Samples from July were set apart in sites 1, 2 and 3.

Depending on the units considered, relative differences in individual weight for each taxa caused discrepancies between ordinations based on biomass or density. For instance, *Dicosmoecus* sp. and *Tipula* sp. contributed to the biomass ordination but very little in the other two ordinations ; *Baetis* sp1, *Cheumatopsyche* sp., *Chironomidae* and *Simulium* spp. showed no correlations at all with the ordination axis when using p/a data. Less common taxa located between both environmental extremes (mouth and outlet) showed some displacement within this area, but the general pattern remained. Number of taxa associated with the downstream sites was much higher in the density and p/a ordinations.

All DCA analyses emphasized a longitudinal and a temporal component to account for variance in the samples, although the relative importance of each axis varied depending on the units considered. Thus, seasonal changes were the most important factor accounting for variance in the biomass analysis while longitudinal changes accounted for a bigger percentage of the variance when using  $\log(\text{density}+1)$  and p/a. Seasonal changes in the macroinvertebrate structure during the study period can be explained in terms of shifts in the relative dominance of certain taxa (see density and biomass ordination) and temporal turnover of species (see p/a ordination). The biomass analysis explained a much higher percentage of the variance and no transformations were needed in contrast to density. Logs were applied to the samples by species matrix to diminish the relative importance of dominant species whose distribution was very skewed to the right. It was noticed that by doing this, certain information was lost in the process and eigenvalues were significantly reduced. For instance, *Baetis* sp1. always exhibited much lower densities in site 4 than in downstream sites, but in July the pattern was reversed. Hundreds of immature individuals were collected almost exclusively in site 4. The transformation of data by taking logs obscured this event. The biomass ordination also failed to show this pattern as differences in individual size in site 4 relative to the other sites masked it. Another change was observed when looking at correlation values between the environmental variables and the ordination scores. Thus, discharge showed very low correlation with the first axis in the untransformed data but it was significantly correlated

after transformation. It appears that by decreasing the relative importance of dominant taxa, certain interactions of less abundant taxa with the environmental variables showed up in the analysis. However, the combined inferences of the three analyses were very useful in explaining and summarizing community structure in the creek. Nevertheless, the ecological information contained in ordination scores as well as evenness or diversity appeared to show more consistent patterns when biomass units were used. Indeed, the use of biomass units has been suggested to be more appropriate than density to describe invertebrate habitat favorability (Miller, 1985), perhaps because of its most closer link to energy units (Wihlm, 1968) which directly determine the relationship of a species with its surrounding environment.

#### Correlation analysis

Flow, temperature, and perhaps water chemistry are the most important controlling factors of benthic communities (Ward & Stanford, 1979). Changes in structure of macroinvertebrate communities below dams have been attributed to temperature (Lehmkuhl, 1972, 1979; Ward, 1974;) or the cumulative influence of different factors (Hilsenhoff, 1971; Spence & Hynes, 1971; Gore, 1980; Voelz, 1989). Relationships between fauna and environmental variables are very often assessed by using multivariate analysis (Cushing et al. 1983, Marchant et al. 1985, Ormerod, 1987). These technics help to find associations between species and environment and represent a first step to elucidate cause and effect relationships between them. Conductivity, temperature, dissolved oxygen,

and nitrates + nitrites were the variables more associated with macroinvertebrates biomass on a seasonal basis (DCA1) (table V). Downstream changes in pH and substrata (table VI) appeared to be associated with changes in community structure from the reservoir to the mouth (DCA2). Axis 1 biomass ordination scores (temporal axis) were significantly correlated ( $p < 0.001$ ) with the first principal component (PCA1, temporal component) of two analyses, one including only chemical variables and the other one including also the substrata size classes (table V, appendix 8). Axis 2 (longitudinal axis) and 3 biomass ordination scores correlated ( $p < 0.001$ ) with PCA2 (longitudinal component) and PCA3 (disturbance component) suggesting certain relation between the biota and physical and chemical variables. On the other hand, DCA performed on log (density+1) and presence/absence emphasized pH,  $\text{NH}_3\text{-N}$ , discharge and substrate. The interpretations of these results are obscured by the high correlations among some of the variables (see appendix 6). The influence of temperature on the life history of aquatic insects has been reported on numerous occasions (eg., Ward & Stanford, 1982; Sweeney, 1984). However, the multivariate analysis did not emphasize temperature as a factor associated with changes in community structure on a longitudinal basis. Probably, the introduction in the analysis of other components of the thermal regime (eg., diel oscillations) would have yielded different results. The relationship between discharge and density has been reported in numerous papers (eg., Minshall and Winger, 1968; O'Hop and Wallace, 1983). Total density was

TABLE VI. Matrix of Pearson correlation coefficients (r), for comparisons between the biomass of selected taxa and physical and chemical variables (two-tailed test).  $r < 0.5$  are not included in the table. When no specified  $n=24$ . For  $n=24$ , 0.51: significant at the 5% level; 0.52-0.62: sig. at the 1% level and  $\geq 0.63$ : sig. at 0.1% level. For  $n=28$  (includes sites above the reservoir), 0.51-0.57 significant at the 1% level;  $\geq 0.61$  significant at the 0.1% level. Dist= distance from the reservoir.

	TEMP	DO	COND	NH <sub>3</sub> -N	NO <sub>3</sub> /2	ALK	SRP	pH	TURB	DISC	PCA1	PCA2	PCA3	DIST.	PN	POC
<i>Simulium</i> spp.	-	-	-	-	-	0.63	-0.54	-	-	-	-0.53	-	-	-	-	-
<i>Hemerodromia</i> sp.	-	-	-	-	-	-	-	-	-0.51	-	-	-	-0.57	-	-0.59	-0.55
Chironomidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dicranota sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Tipula</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Brachycentrus</i> sp.	-	-	-	-0.61	-	-	-	0.62	-	-	-	0.52	-	0.79	-	-
<i>Dicosmoecus</i> sp.	0.61	-0.61	-0.70	-	-	-0.52	-	-	-	-	0.67	-	-	-	-	-
<i>Cheumatopsyche</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. occidentalis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>H. cockerelli</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.56	-	-
<i>Baetis</i> sp1.	-0.55	0.55	0.60	-	-	-	-	-	-	-	-0.51	-	-	-	-	-
<i>E. inermis</i>	-	-	0.58	-	0.51	-	-	-0.60	-	-	-	-0.63	-	-0.61	-	-
<i>C. sabulosa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	0.69	-	-
<i>S. parallella</i>	-	-	-	-0.54	-	0.51	-0.57	-	-	-	-	-	-	-	-	-
<i>Optioservus</i> spp.	-	-	-	-	-	-	-	0.66	-	-0.63	-	0.59	-	0.72	-	-
<i>Z. parvula</i>	-	-	-	-	-	-	-	0.66	-	-0.57	-	0.56	-	0.80	-	-
<i>Petrophila</i> sp.	-	-	-	-	-	-	-	0.66	-	-	-	-	-	0.66	-	-
<i>Oligochaeta</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tot. Density	-	-	-	-0.61	-	-	-0.57	-	-	-	-	-	-0.60	-	-0.50	-
Tot. Density (n=28)	-	-	-	-	-	-	-	0.52	-	-	-	-	-	-	-	-
Tot. Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tot. Biomass (n=28)	-	-	0.79	-	0.51	0.77	-	0.56	-	-	-	-	-	-	-	-



negatively correlated with the third principal component which was related to increases in turbidity,  $\text{NH}_3\text{-N}$  and SRP (table VI). This seems to agree with Rosenberg and Wiens (1978) who showed that addition of sediment to a stream increases drift. Number of individuals for all the regulated sites exhibited a strong trend to decline over time between November and April to recover thereafter (figure 7A). Changes in biomass over time (with the exception of site 4) did not follow this pattern (figure 7B). Probably several factors were involved in this trend, including a concomitant decrease in aquatic angiosperms (a potential food supply and shelter for macroinvertebrates) for the same period of time. The low gradient of pH in the tailwaters suggest that if there was an effect on community structure in the creek it must have been very subtle. Natural variations in water chemistry are rarely as important as temperature, flow or substrate in structuring stream communities (Ward, 1985). In this case, the nutrient enrichment of the waters of Crow Creek appear to be important in controlling community structure through the enhancement of aquatic vegetation which provide substrate, shelter and food for aquatic organisms. The importance of sedimentation should not be overlooked.

Individual taxa differed in their relationships with the selected physical and chemical variables (table VI). The most highly correlated taxa were *Dicosmoecus* sp., *Baetis* sp1., *Ephemerella inermis*, *Optioservus* spp. and *Zaitzevia parvula*. Some of the dominant taxa in the creek showed

very low correlations with the selected physical and chemical variables (eg., *Hydropsyche occidentalis* and *Cheumatopsyche* sp.). Perhaps the environmental gradient was not strong enough to trigger a response. Habitat characteristics, especially substrata, appear to be more important. Relatively high correlations between some taxa (particularly *Brachycentrus* sp., *Optioservus* spp. and *Zaitzevia parvula*) and the distance from the reservoir appear to reveal a possible response to some kind of environmental gradient. Examples of high correlations between environmental variables and biota do not necessarily mean cause and effect relationships (see Minshall & Minshall, 1978; Willoughby and Mappin, 1988). As pointed out above, it is not possible to establish causal mechanisms from the information available. Detailed information on the life histories of the species involved and field and laboratory experiments would be needed. An interesting approach would be to compare life histories of identical species occurring in the area in different environments ranging from pristine to impacted conditions. A deviation from the expected pattern (natural conditions) could lead to identification of key controlling factors for a particular species.

## CONCLUSIONS

It is apparent that the impoundment of Crow Creek and agricultural activities in the area have had a considerable influence on the system. Problems derived from agricultural run-off and regulation clearly overlapped. The tailwaters exhibited typical effects of regulation produced below hypolimnial release reservoirs: modified thermal regime, altered hydrograph and reduced biodiversity. In addition and due to the specific characteristics of the reservoir (eg., shallowness, unprotected shorelines) and the additive effect of agricultural run-off, marked changes in turbidity and nutrient concentrations occurred below the reservoir. As a result, the nature of the substrata is altered and hence the aquatic biota associated with it. Nevertheless, a remanant fauna of a Palouse Prairie stream still occurs in the creek, particularly at the confluence of the creek with the Flathead River and above the reservoir. Effects on trout populations seem to be more complex but appear to be related to the combined effect of regulation and agricultural run-off on water and habitat quality in the creek. These impacts cannot be eliminated if their causes are not ameliorated. However, irrigation, regulation and fisheries are not necessarily incompatible, but an integrative approach that involves best management options is needed.

## RECOMMENDATIONS

Water quality in the reservoir (in terms of algae cover and turbidity) was apparently better in past years (Jay Johnson, personal communication). The possibilities of improving water quality in the tailwaters are restricted as water is released by a single hypolimnial outlet. Temperature, turbidity and nutrient enrichment problems would improve if water were withdrawn from a multilevel outlet. Moreover, the regulation of the amount of water released through the outlet does not appear to have a significant influence on water quality. Only two parameters were significantly correlated with discharge: pH ( $r=-0.50$ ,  $p<0.001$ ) and  $\text{NH}_3\text{-N}$  ( $r=0.44$ ,  $p<0.01$ ) (see appendix 7). An understanding of how the retention time influences water quality characteristics is needed to design a water release schedule that maximizes water quality in the tailwaters.

It appears that reducing the inflow of nutrients in the reservoir and the tailwaters by controlling point and non point nutrient and sediment sources above and below the reservoir would contribute to mitigating the human impact on the system. Five reclamation alternatives for mitigating sedimentation could be applied in Crow Creek: (1) the maintenance of a more natural nearstream vegetation and channel morphology (*sensu* Karr and Schlosser, 1978). This approach has been effective in improving stream "fishability" in agricultural watersheds (Karr and Gorman, 1975); (2) the use of bank protection devices, which function by either diverting the flow away from the bank or stabilizing the eroding banks (Swales, 1989); (3) the implementation

of periodic flushing flows timed to take into account the species (fish and macroinvertebrates) present in the system, the life-history requirements of the important species, the historical run-off period and flow availability at the time (Reiser et al, 1989); (4) the installation of deflectors in the channel in order to increase water velocity and remove silt from spawning gravels and critical areas for macroinvertebrate production (Wesche, 1985) (5) The removal of beavers and beaver dams from the creek which result in sediment traps.

To conclude it is noteworthy to emphasize that due to the uniqueness of the Palouse prairie biotope, any management alternative to be applied in Crow Creek should take into account the macroinvertebrate fauna if the biodiversity of the system is to be preserved.

## LITERATURE CITED

- American Public Health Association. 1985. Standard methods for the examination of water and wastewater. 16th ed. Washington, D.C. 1268 pp.
- Armitage, P.D. 1984. Environmental changes induced by stream regulation and their effect on lotic macroinvertebrate communities, pp. 139-166. IN: Lillehammer, A. and Saltveit, S.J. (eds.), Regulated Rivers. Universitetsforlaget AS, Oslo.
- Armour, C. L., Burnhan, K. P. and Platts, W. S. 1983. Field methods and statistical analysis for monitoring small salmonid streams. U.S. Fish and Wildlife Service.
- Bisson, P. A., Nielsen, J. L., Palmason, R. A. and Grove, L. E. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. pp 62-73. IN: Armantrout, N. B. (ed.), Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. Western Division, American Fisheries Society, Portland, Oregon, U.S.A.
- Brittain, J. E. and Salveit, S. J. 1989. Effect of river regulation on mayflies. Regulated Rivers: Research & Management 3:191-204.
- Cordone, A. J. and Kelly, D. W. 1961. The influence of inorganic sediment on the aquatic life of streams. Calif. Fish and Game. 47: 189-229.
- Cross, D. T., DosSantos, J. 1988. Lower Flathead system fisheries study- Executive Summary, Volume I. Final Report FY 1983-1987. Bonneville Power Administration, Portland, Oregon.
- Cushing, C. E., McIntyre, C. D., Cummins, K. W., Minshall, G. W., Petersen, R. C., Sedell, J. R. and Vannote, R. L. 1983. Relationships among chemical, physical, and biological indices along river continua based on multivariate analysis. Arch. Hydrobiol. 98:317-326.
- D'Elia, C. F., Steudler, P. A. and Corwin, N. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22(4):760-764.
- DosSantos, J. M., Darling, J. E. and Cross, D. 1988. Lower Flathead system fisheries study: main river and tributaries, Volume II. Final Report FY 1983-1987. Bonneville Power Administration, Portland, Oregon.
- Edwards, R. J. 1978. The effect of hypolimnion reservoir releases on fish distribution and species diversity. Trans. Am. Fish. Soc. 107(1):71-77.

- EPA. 1985. Part II. Water Quality Criteria; Availability of documents; Notice. Federal Register/ vol. 50(145):30784-30796/Monday, July 29, 1985/ Notices.
- Gauch, H. G. 1982. Multivariate analysis in community ecology. Beck, E., Birks, H. J. B. and Connor, E. F. (eds.). Cambridge University Press, Cambridge. 298 pp.
- Gore, J. A. 1980. Ordination analysis of benthic communities upstream and downstream of a prairie storage reservoir. *Hydrobiologia* 69:33-44.
- Hannan, H. H. 1979. Chemical modifications in reservoir-regulated streams, pp. 75-94. IN: Ward, J. V. and Stanford, J. A. (eds.), *The Ecology of Regulated Streams*. Plenum Press, New York and London.
- Hauer, F. R. and Stanford, J. A. 1981. Larval specialization and phenotypic variation in *Artopsyche grandis* (Trichoptera: Hydropsychidae). *Ecology* 62:645-653.
- Hauer, F. R. and Stanford, J. A. 1990. Distribution and abundance of Trichoptera in a large regulated river. *Verh. Internat. Verein. Limnol.* 24:in press.
- Hewlett-Packard, F&M Model 185 CHN Analyzer. 1971.
- Hill, M. O., 1979b. DECORANA- a FORTRAN program for detrended correspondance analysis and reciprocal averaging. *Ecology and Systematics*, Cornell University, Ithaca, New York 14850, U.S.A.
- Hilsenhoff, W. L. 1971. Changes in the downstream insect and amphipod fauna caused by an impoundment with a hypolimnion drain. *Ann. Ent. Soc. Am.* 64 (3):743-746.
- Holden, P. B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River, pp. 57-74. IN: Ward, J. V. and Stanford, J. A. (eds.), *The Ecology of Regulated Streams*. Plenum Press, New York and London.
- Hynes, H. B. N. 1973. The effects of sediments on the biota in running waters, pp. 653-663. IN: *Fluvial processes and sedimentation. Proceedings of Hydrology Symposium held at University of Alberta, Edmonton, May 8 and 9, 1973.* Canada Department of the Environment, Ottawa, Canada. 759 pp.
- Johnson, R. A. and Wichern, D. W. 1988. *Applied Multivariate Statistical Analysis*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 607 pp.

- Karr, J. R. and Gorman, O. T. 1975. Non-point source pollution seminar. EPA 905/9-75-007, Environmental Protection Agency, Chicago.
- Karr, J. R. and Schlosser, I. J. 1978. Water resources and the land-water interface. *Science* 201:229-234.
- Krebs, C. J. 1985. *Ecology: The Experimental Analysis of Distribution and Abundance*, 3th Ed. Harper & Row, New York, 800 pp.
- Lehmkuhl, D. M. 1972. Changes in the thermal regime as a cause of reduction of benthic fauna downstream of a reservoir. *J. Fish. Res. Bd. Can.* 29: 1329-1332.
- Lehmkuhl, D. M. 1979. Environmental disturbance and life histories: principles and examples. *J. Fish. Res. Bd. Can.* 36:329-334.
- McCune, B. 1989. Multivariate analysis on the PC-ORD system. Holcomb Research Institute. Butler University. HRI Report No. 75.
- Marchant, R., Metzeling, L., Graessner, A. and Suter, P. 1985. The organization of macroinvertebrate communities in the major tributaries of the LaTrobe River, Victoria, Australia. *Freshwater Biol.* 15:315-331.
- Miller, C. 1985. Correlates of habitat favourability for benthic macroinvertebrates at five stream sites in an Appalachian Mountain drainage basin, U.S.A. *Freshwater Biology*. 15:709-733.
- Minshall, G. W. and Winger, P. V. 1968. The effect on reduction of stream flow on invertebrate drift. *Ecology*. 49:580-582.
- Minshall, G. W. & Minshall, J. N. 1977. Microdistribution of benthic invertebrates in a Rocky Mountain Stream. *Hydrobiologia*. 55 3:231-249.
- Minshall, G. W. & Minshall J. N. 1978. Further evidence on the role of chemical factors in determining the distribution of benthic invertebrates in the River Duddon. *Arch. Hydrobiol.* (83) 3:324-355.
- O'Hop, J. and Wallace, J. B. 1983. Invertebrate drift, discharge, and sediment relations in a southern Appalachian headwater stream. *Hydrobiologia*. 98:71-84.
- Ormerod, S. J. 1987. The influences of habitat and seasonal sampling regimes on the ordination and classification of macroinvertebrate assemblages in the catchment of the river Wye, Wales. *Hydrobiologia*. 150:143-151.



- Perry, S. A. and Sheldon, A. L. 1986. Effects of exported seston on aquatic insect faunal similarity and species richness in lake outlet streams in Montana, U.S.A. *Hydrobiologia* 137:65-77.
- Pfister, R. D., Kovalchic, B. L., Arno, S. F. and Presby, R. C. 1977. Forest habitat types of Montana. USDA Forest Service General Technical Report INT-34. Intermountain Forest and Range Experiment Station, Ogden, UT.
- Reiser, D. W., Ramey, M. P. and Wesche, T. A. 1989. Flushing Flows. IN: Gore, J. A. and Petts, G. E. (eds.), *Alternatives in Regulated River Management*. CRC Press, Inc. Boca Raton, Florida. 344 pp
- Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.* 191:382 pp.
- Ridley, J. E. and Symons, J. M. 1972. New approaches to water quality control in impoundments, pp.389-412. IN: Mitchel, R. (ed.), *Water Pollution Microbiology*. John Wiley and Sons, INC., New York.
- Ringo, R. D. and Halfmoon, F. L. 1990. Progress report: Lower Crow Creek fishery restoration. Bureau of Indian Affairs. Portland, OR.
- Rosenberg, D. M. and Wiens, A. P. 1978. Effects of sediment addition on macrobenthic invertebrates in a northern Canadian river. *Water Research*. 12:753-63.
- Ross, C. P. 1959. Geology of Glacier National Park and the Flathead Region, Northwestern Montana. U.S. Geological Survey, Professional Paper #296.
- Sheldon, A. L. and Haick, R. A. 1981. Habitat selection and association of stream insects: a multivariate analysis. *Freshwater Biology*. 11:395-403.
- Simons, D. B. 1979. Effects of stream regulation on channel morphology, pp. 95-111. IN: Ward, J. V. and Stanford, J. A. (eds.), *The Ecology of Regulated Streams*. Plenum Press, New York and London.
- Spence, J. A. and Hynes, H. B. N. 1971. Differences in benthos upstream and downstream of an impoundment. *J. Fish. Res. Board Can.* 28:35-43.
- Stanford, J. A., Hughes, J. L., Jourdonnais, J. H. and Ellis, B. K. 1986. Methodology for limnological analyses and quality control procedures used in the Freshwater Research Laboratory. Open File Report. Flathead Lake Biological Station, University of Montana, Polson, Montana.

- Stanford, J. A. and Ward, J. V. 1983. Insect species diversity as a function of environmental variability and disturbance in stream systems, pp. 265-278. IN: Barnes, J. R. and Minshall, G. W. (eds.), Stream Ecology. Plenum Press, New York. 399 pp.
- Stanford, J. A. 1990. Mitigating the impacts of stream and lake regulation in the Flathead River Basin, Montana: an ecosystem perspective. Open file Report Number 113-90. Flathead Lake Biological Station, University of Montana, Polson.
- Swales, S. 1989. The use of instream habitat improvement methodology in mitigating the adverse effects of river regulation on fisheries. pp. 185-208. IN: Gore, J. A. and Petts, G. E. (eds.), Alternatives in Regulated River Management. CRC Press, Boca Raton, Florida. 344 pp.
- Sweeney, B. W. 1984. Factors influencing life-history patterns of aquatic insects, pp. 56-100. IN: Resh, V. H. and Rosenberg, D. M. (eds.), The Ecology of Aquatic Insects. Greenwood Press, New York. 625 pp.
- Ter Braak, C. J. F. and Prentice, I. C. 1988. A theory of gradient analyses. *Advances in ecological research* 18:271-317.
- Ter Braak, C. J. F. 1989. CANOCO- an extension of DECORANA to analyze species-environment relationships. *Hydrobiologia* 184:169-170.
- Trotzky, H. M. and Gregory, R. W. 1974. The effects of water flow manipulation below a hydroelectric power dam on the bottom fauna of the Upper Kennebec River, Maine. *Trans. Am. Fish. Soc.* 103:318-324.
- Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R. and Cushing, C. E. 1980. The River Continuum Concept. *Can. J. Fish. Aquat. Sci.* 37:130-137.
- Voelz, N. J. and Ward, J. V. 1989. Biotic and abiotic gradients in a regulated high elevation Rocky Mountain River. *Regulated Rivers: Research & Management.* 3:143-152.
- Ward, J. V. 1974. A temperature-stressed stream ecosystem below a hypolimnial release mountain reservoir. *Arch. Hydrobiol.* 74(2):247-275.
- Ward, J. V. 1976a. Effects of flow patterns below large dams on stream benthos: A review, pp. 225-253. IN: Orsborn, J.F. and Allman, C. H. (eds.), Instream Flow Needs Symposium, Vol. II. Am. Fish. Soc., Bethesda, Maryland.

- Ward, J. V. 1976b. Comparative limnology of differentially regulated sections of a Colorado Mountain River. Arch. Hydrobiol. 78(3):312-319.
- Ward, J. V. 1984. Ecological perspectives in the management of aquatic insect habitat, pp. 558-577. IN: Resh, V. H. and Rosenberg, D. M. (eds.), The Ecology of Aquatic Insects. Plenum Press, New York and London.
- Ward, J. V. 1985. An illustrated guide to the mountain stream insects of Colorado. Fort Collins, CO. 199pp.
- Ward, J. V. and Stanford, J. A. 1979. Ecological factors controlling stream zoobenthos with emphasis on thermal modification of regulated streams, pp. 35-55. IN: Ward, J. V. and Stanford, J. A. (eds.), The Ecology of Regulated Streams. Plenum Press, New York and London.
- Ward, J. V. and Stanford, J. A. 1982. Thermal responses in the evolutionary ecology of aquatic insects. Annual Review of Entomology. 27:97-117.
- Ward, J. V. and Stanford, J. A. 1990. Ephemeroptera of the Gunnison River, Colorado, U.S.A. pp. 215-220. IN: Campbell, I. C. (ed.), Mayflies and Stoneflies. Kluwer Academic Publishers.
- Wesche, T. A. 1985. Stream channel modifications and reclamation structures to enhance fish habitat, pp. 103-163. IN: Gore, J. A. (ed.). The Restoration of Rivers and Streams. Butterworth Publishers, Stoneham, MA 02180.
- Wihlm, J. L. 1968. Use of biomass units in Shannon's formula. Ecology 49:153-156.
- Wilkinson, L. SYSTAT: The System for Statistics. Evanston, IL: SYSTAT, Inc. 1988.
- Willoughby L. G. and Mappin R. G. 1988. The distribution of Ephemerella Ignita (Ephemeroptera) in streams: the role of pH and food resources. Freshwater Biology. 19:145-155.
- Winget, R. N. 1985. Methods for determining successful reclamation of stream ecosystems, pp. 165-192. IN: Gore, J. A. (ed.). The Restoration of Rivers and Streams. Butterworth Publishers, Stoneham, MA 02180.
- Zimmermann, H. J. and Ward, J. V. 1984. A survey of regulated streams in the Rocky Mountains of Colorado, U.S.A., pp. 251-259 IN: Lillehammer, A. and Salveit S. J. (eds.), Regulated Rivers. Universitetsforlaget, Oslo.

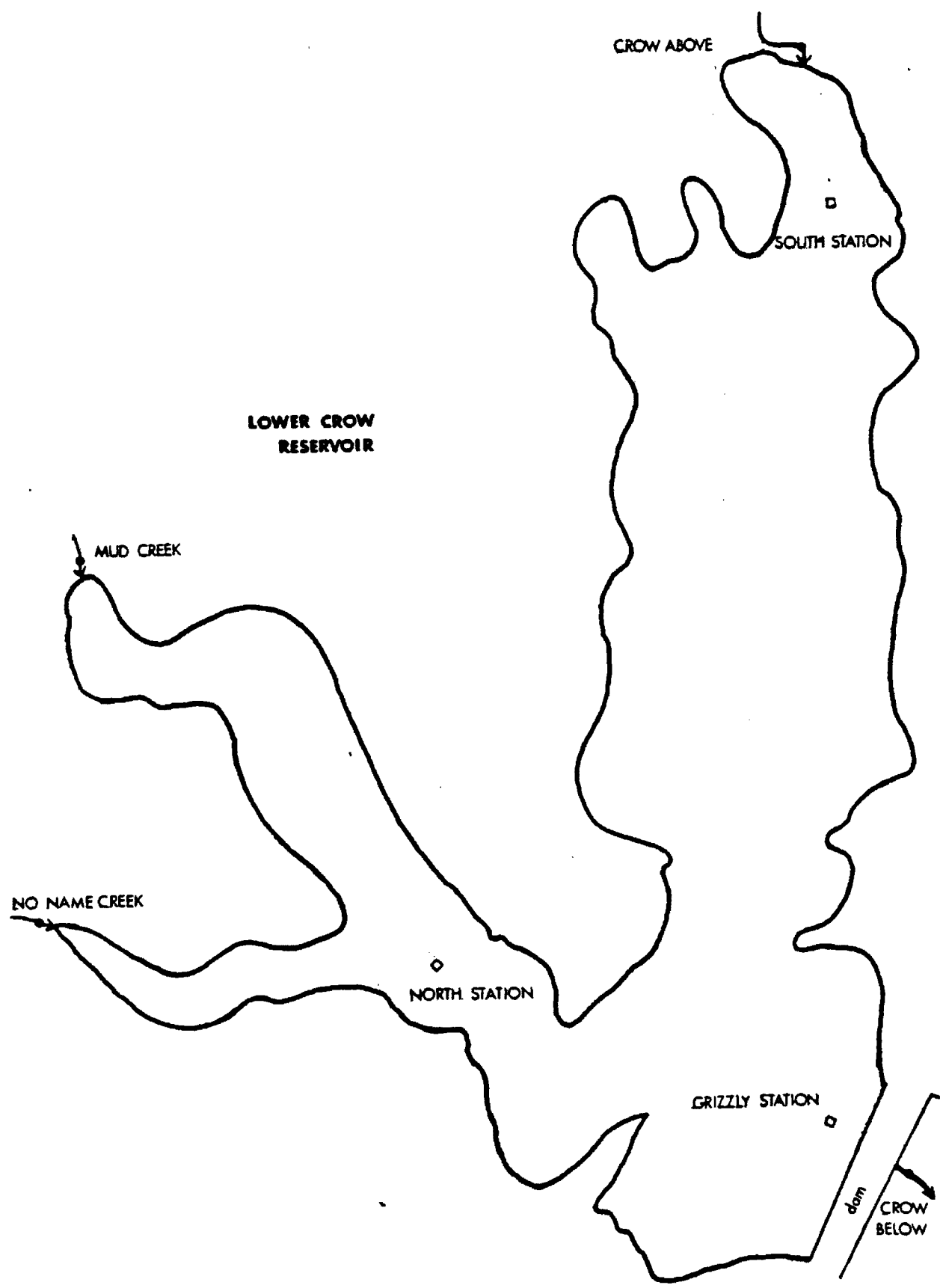
## APPENDIX 1. Physical and chemical data for site 7.

	MAY	JUNE	JULY	AUGUST
Temperature (°C)	15.70	15.20	15.30	18.90
pH	8.34	8.28	8.22	8.22
DO (mg/l)	8.80	8.60	8.60	8.40
% oxygen saturation	98.06	94.79	94.98	99.82
Specific cond. (uohms/cm)	425.00	309.00	285.00	268.00
Alkalinity (mg CaCO <sub>3</sub> /l)	203.50	152.90	143.00	134.20
Turbidity (NTU)	5.50	15.00	4.90	11.00
TSS (mg/l)	20.60	30.30	7.80	27.80
NH <sub>3</sub> -N (ug/l)	168.00	35.10	21.70	30.10
NO <sub>2</sub> /3 (ug/l)	1091.00	416.00	271.00	240.00
TPN (ug/l)	1579.00	1020.00	836.00	794.00
SRP (ug/l)	4.40	16.00	23.70	-
TP (ug/l)	37.30	82.90	56.10	157.00

APPENDIX 2. Percentage composition of five size classes of substrata for all the study sites.

	POSITION	BOULDER	COBBLE	PEBBLE	GRAVEL	SAND
SITE1	MIDDLE	34.6+26.6	55.0+29.1	14.2+ 9.1	1.8+0.8	0.0+0.0
	SUBMIDDLE	10.0+22.4	39.0+27.2	45.6+31.6	3.4+4.2	0.0+0.0
	BANK	25.0+35.6	55.0+41.2	17.2+20.2	2.7+3.2	0.0+0.0
SITE2	MIDDLE	20.0+12.2	63.6+ 6.9	14.4+ 5.2	2.0+ 2.7	0.0+0.0
	SUBMIDDLE	4.0+ 8.9	74.0+11.4	17.4+ 9.8	4.6+ 3.5	0.0+0.0
	BANK	0.0+ 0.0	35.8+15.6	45.0+12.6	15.0+10.9	2.5+4.2
SITE3	MIDDLE	47.0+43.1	31.6+25.2	16.0+19.2	5.4+ 2.9	0.0+0.0
	SUBMIDDLE	37.0+21.7	30.0+23.7	29.0+14.7	3.0+ 2.7	0.0+0.0
	BANK	4.0+ 8.9	73.0+18.2	17.5+14.1	5.5+ 2.7	0.0+0.0
SITE4	MIDDLE	18.3+18.3	72.5+16.0	6.0+ 5.5	2.4+ 1.4	0.7+1.1
	SUBMIDDLE	16.7+20.4	75.2+21.7	0.0+ 0.0	6.0+ 3.9	2.2+2.3
	BANK	4.2+10.2	62.5+25.6	13.7+18.6	16.0+14.1	3.7+4.0
SITE5	MIDDLE	56.2+ 9.5	35.0+ 8.2	8.25+4.3	0.5+ 0.6	0.0+0.0
	SUBMIDDLE	15.0+33.5	49.0+35.1	30.8+19.8	5.2+ 3.2	0.0+0.0
	BANK	5.0+10.0	77.5+22.5	15.5+11.1	2.0+ 2.1	0.0+0.0
SITE6	MIDDLE	14.0+31.3	57.0+27.3	24.6+21.2	4.4+ 3.4	0.0+0.0
	SUBMIDDLE	0.0+ 0.0	56.0+13.9	26.0+16.3	16.0+ 5.5	0.0+0.0
	BANK	7.0+10.9	68.0+11.5	21.4+19.5	14.6+14.1	0.0+0.0

APPENDIX 3. Map of Lower Crow Reservoir.



APPENDIX 4. Percentage riffle, run and pool for each site. 400 meter segments were surveyed for sites 1, 2 and 3, and 225 meters for site 4. Percentages are based on area within each site.

	SITE 1	SITE 2	SITE 3	SITE 4
RIFFLE	25.23	20.04	22.06	28.40
RUN	52.91	66.85	42.96	55.40
POOL	21.86	13.11	34.98	16.20

APPENDIX 5A. Physical and chemical data for three stations at the reservoir, tributaries and outlet measured in July 14, 1989. See map in appendix 3 to locate sampling sites.

GRIZZLY STATION (time:0127)

DEPTH (m)	TEMP. (OC)	pH	DO (mg/l)	COND (umhos) /m)	TURB (N.T.U)	TSS (mg/l)	SECCI DISK (m)
0.1	24.16	9.62	12.83	168	4.30	4.17	1.75
1	22.83	9.55	13.20	168	9.65	8.84	
2	22.05	9.40	10.58	169			
3	21.26	8.95	6.55	174			
4	21.00	8.75	4.83	190			
5	20.65	8.58	4.15	193			
6	20.18	8.36	4.00	199	3.50	2.14	
7	19.67	8.26	4.28	201			
8	19.20	8.15	3.79	205	3.20	2.30	
9	18.95	8.10	3.74	207			
10	18.60	7.96	3.23	210			
11	18.36	7.83	2.64	211	3.05	2.34	
12	18.16	7.84	2.96	212	3.45	2.85	

SOUTH STATION (time:1500)

0.1	25.65	9.67	13.16	163			1.10
1	23.30	9.62	15.65	164	19.50	28.22	
2	22.26	9.41	11.80	163			
3	21.90	9.17	9.98	164	22.50	51.28	
4	20.91	8.50	7.67	169			

NORTH STATION (time:1655)

0.1	25.61	9.54	11.82	170			1.40
1	23.26	9.73	14.89	167	11.00		
2	22.10	9.32	9.97	168			
3	21.82	9.21	8.71	167	7.95		
4	21.34	8.75	5.27	196			
5	21.10	8.64	5.17	204	15.00		
6	20.18	7.99	2.55	226			
7	19.83	8.06	2.66	207	10.50	13.42	
8	19.36	8.05	1.77	208			
9	19.04	7.76	0.34	214	7.65		

CROW ABOVE (time:1732)

23.29 8.46 7.85 163 5.00 15.78

CROW BELOW (time:1841)

17.79 7.76 8.72 216 6.15 5.52

MUD CREEK (time:1115)

24.27 8.45 8.93 270 27.50 122.98

NO NAME CREEK (time:15:45)

27.01 8.39 7.51 238 41.50 -



APPENDIX 5B. Physical and chemical data for three stations at the reservoir, tributaries and outlet measured in August 31, 1989.

GRIZZLY STATION (time:1356)

DEPTH (m)	TEMP. (OC)	pH	DO (mg/l)	COND (umhos /m)	TURB (N.T.U)	TSS (mg/l)	SECCI DISK (m)
0.1	20.96	9.02	8.60	209	10.00	5.75	1.80
1	19.20	9.02	8.39	207	11.50	5.75	
2	18.91	8.91	7.28	208			
3	18.84	8.94	7.64	208	9.30	5.00	
4	18.75	8.70	5.21	212			
5	18.58	8.52	4.67	215	4.70	2.62	
6	18.42	8.35	4.12	225			
7	18.35	8.22	3.43	239	7.40	2.87	
8	18.17	8.21	3.72	244			
9	18.07	8.12	3.08	248	8.80	3.41	
10	17.91	8.10	3.40	255			
11	17.87	8.07	3.01	258	8.05	4.62	
12	17.82	8.09	3.38	259			
13	17.75	8.05	3.77	262			

SOUTH STATION (time:1306)

0.1	20.34	8.94	7.64	202	8.90	5.59	1.57
1	18.69	8.96	7.79	201	9.75	6.21	
2	18.54	8.97	7.96	201			
3	18.33	8.94	7.71	202	6.50	6.75	
4	17.87	8.82	7.22	204			

NORTH STATION (time:1053)

0.1	18.69	8.93	8.54	211	10.00	7.25	1.80
1	18.54	8.97	8.40	210	8.50	5.75	
2	18.50	8.98	8.32	209			
3	18.48	8.96	7.97	210	8.40	3.37	
4	18.47	8.85	7.42	213			
5	18.38	8.78	6.87	222	9.50	6.50	
6	18.29	8.78	6.81	228			
7	18.03	8.75	6.97	232	13.00	11.62	
8	18.17	8.67	6.78	233		13.50	
9	18.03	8.63	6.89	237	25.00	37.12	

CROW ABOVE (time:1234)

15.98 8.49 9.51 211 3.20 2.00

CROW BELOW (time:1841)

17.74 8.27 8.48 272 44.00 75.72

MUD CREEK (TIME:1115)

13.40 8.33 9.06 424 28.00 21.29

NO NAME CREEK (time:15:45)

14.01 8.48 10.28 434 8.50 5.00

APPENDIX 6. Fish population estimates for spring and fall, 1989. (a) Peterson mark and recapture (95% confidence limit); (b) two pass removal method (95% confidence limit); (c) total count. Biomass (kg) is given in parenthesis.

\* M.C < N (biased estimate).

SPECIES	SPRING 89			FALL 89		
	SECTION 1	SECTION 3	SECTION 4	SECTION 1	SECTION 3	SECTION 4
LARGESCALE SUCKER (0-260mm)	40 <sup>c</sup> (0.9)	7 <sup>c</sup> (0.2)	1 <sup>c</sup> (0.003)	64 <sup>c</sup> (1.7)	324 <sup>a</sup> +279 (6.5)	1 <sup>c</sup> (0.004)
(280-560mm)	777 <sup>a</sup> +318 (729.8)	9 <sup>c</sup> (8.7)	0 (0.0)	224 <sup>a</sup> +116 (173.2)	9 <sup>c</sup> (4.5)	5 <sup>c</sup> (7.2)
SQUAWFISH all sizes	24 <sup>c</sup> (0.9)	1 <sup>c</sup> (.008)	0 (0.0)	*95 <sup>c</sup> (7.7)	13 <sup>c</sup> (0.6)	0 (0.0)
>220mm	1 <sup>c</sup> (0.7)	0 (0.0)	0 (0.0)	20 <sup>c</sup> (5.6)	2 <sup>c</sup> (0.4)	0 (0.0)
MOUNTAIN WHITEFISH all sizes	15 <sup>c</sup> (2.5)	1 <sup>c</sup> (0.23)	0 (0.0)	9 <sup>c</sup> (0.8)	11 <sup>c</sup> (0.8)	1 <sup>c</sup> (0.2)
>200mm	9 <sup>c</sup> (2.1)	1 <sup>c</sup> (0.23)	0 (0.0)	3 <sup>c</sup> (0.6)	3 <sup>c</sup> (0.4)	1 <sup>c</sup> (0.2)
LONGNOSE DACE all sizes	31 <sup>c</sup> (0.1)	55 <sup>c</sup> (0.5)	1 <sup>c</sup> (0.1)	15 <sup>c</sup> (0.1)	101 <sup>c</sup> (0.6)	5 <sup>c</sup> (0.03)
>65mm	24 <sup>c</sup> (0.1)	54 <sup>c</sup> (0.5)	0 (0.0)	15 <sup>c</sup> (0.1)	*93 <sup>c</sup> (0.6)	5 <sup>c</sup> (0.03)
REDSIDE SHINER (35-90mm)	20 <sup>c</sup> (0.08)	0 (0.0)	0 (0.0)	61 <sup>c</sup> (0.3)	*11 <sup>c</sup> (0.05)	0 (0.0)
(90-140mm)	17 <sup>c</sup> (0.1)	1 <sup>c</sup> (0.02)	0 (0.0)	57 <sup>c</sup> (0.6)	20 <sup>c</sup> (0.3)	0 (0.0)
YELLOW PERCH (50-150mm)	4 <sup>c</sup> (.04)	*17 <sup>c</sup> (0.08)	6 <sup>c</sup> (0.02)	*22 <sup>c</sup> (0.2)	959 <sup>a</sup> +543 (16.0)	22 <sup>c</sup> (0.3)
(160-230mm)	5 <sup>c</sup> (0.5)	0 (0.0)	0 (0.0)	0 (0.0)	9 <sup>c</sup> (0.8)	4 <sup>c</sup> (0.2)
BULLHEAD all sizes	0 (0.0)	1 <sup>c</sup> (0.05)	1 <sup>b</sup> +0 (0.05)	4 <sup>c</sup> (0.5)	1 <sup>c</sup> (0.1)	1 <sup>c</sup> (0.05)
LARGEMOUTH BASS all sizes	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 <sup>c</sup> (0.44)

TEMP	1.00	pH	DO	%SAT	COND	ALK	TURB	DISC	NH <sub>3</sub> -N	NO <sub>2</sub> /3	SRP
pH	-	1.00	-	-	-	-	-	-	-	-	-
DO	-0.90	-	1.00	-	-	-	-	-	-	-	-
%SAT	0.38	0.51	-0.07	1.00	-	-	-	-	-	-	-
COND	-0.81	-	0.89	-	1.00	-	-	-	-	-	-
ALK	-0.61	-	0.74	-	0.87	1.00	-	-	-	-	-
TURB	-	-	-	-	-	-	1.00	-	-	-	-
DISC	-	-0.50	-	-	-	-	-	1.00	-	-	-
NH <sub>3</sub> -N	-	-0.49	-	-	-	-0.40	-	0.44	1.00	-	-
NO <sub>2</sub> /3	-0.73	-	0.77	-	0.80	0.71	-	-0.38	-	1.00	-
SRP	0.38	-	-0.35	-	-0.45	-0.75	-	-	0.65	-0.46	1.00

APPENDIX 8. (A) PCA of water chemistry, temperature discharge, and DCA scores. (B) same as above but also including the substrata. Only significant values are shown (n=72). .308-.397 significant at the 1% level. >.421 sig. at the 0.1% level (two tailed test).

	(A)			(B)		
	PCA1	PCA2	PCA3	PCA1	PCA2	PCA3
Temperature	.870	-	-	-.849	-	-
pH	-	-.755	-.396	-.452	.602	.357
DO	-.884	-	-	.877	-	-
% O <sub>2</sub> sat.	.421	-.308	-	-.452	-	-
Conductivity	-.932	-	-	.906	-	-
Alkalinity	-.798	-.504	-	.659	.540	.397
Turbidity	-	-	-.659	-	-	-
Discharge	-	.638	.352	-	-.553	-
NH <sub>3</sub> -N	-	.959	-	-	-.680	-.591
NO <sub>2</sub> /3	-.869	-	-	.832	-	-
SRP	.533	.711	-	-.364	-.587	-.548
DCA1	.586	-.399	-	-.682	-	-
DCA2	-	-	-.820	-	.486	-
DCA3	-	.623	-	-	-.499	-.423
Boulder				-	.347	-.662
Cobble				-	-.375	-
Pebble				-	.450	-
Gravel				-	-.522	.620
Sand				-	-.692	.518
Porosity				-	-.625	.584